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A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the Plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Frederick A. G. Muir:

An historical account of the extremely valuable work of Dr. Muir in the introduction of natural enemies for the biological control of the major insect pests of sugar cane in Hawaii. Chief among these pests were the sugar cane leafhopper, the Anomala root grub, and the New Guinea sugar cane beetle borer. Reference is also made to Dr. Muir's work in systematic entomology, which dealt chiefly with the important group of leafhoppers and their allies. A bibliography of Dr. Muir's published works is included.

Width of Cane Rows:

The question often arises, "How far apart do they make their cane rows in that country, and does the width increase or decrease yields?" In this article we have drawn our data from other countries and present them along with what data we have from our own files.

Climate in Relation to Sugar Production:

This article is a general survey of an admittedly big subject. It shows by means of some interesting and simple charts the great differences in sugar production that can be caused by changes in weather conditions, and suggests that climate be considered a factor of major importance in our cane agriculture.

The Significance of Climatic Differences Among the Sugar Plantations of Hawaii:

Some plantations grow H 109, others Yellow Caledonia; some have generally good juices, others poor—why? It may be due to differences in soil, in water, or other factors. This article brings out certain interesting relationships which seem

to suggest that some of these differences could be due to differences in climatic conditions.

Field Experiment Technique:

The various problems related to the technique of conducting field experiments are dealt with in a comprehensive paper now published with the revisions that followed preliminary circulation inviting suggestions and criticisms.

Notes on Interpreting Experimental Results:

One of the most perplexing problems connected with field experiments is the process by which a logical and proper interpretation of the harvesting results is obtained.

A few of the methods and hints are suggested for excluding the irrational harvesting data and for interpreting the experimental results.

Studies in Experimental Technique:

A study of the data secured from the 1931 Blank Test, harvested at Hakalau Plantation Company, is offered to show how such factors as the size and shape of plot, and the number of replications, can affect the accuracy of our field experiments.

Some Mononchs of Hawaii:

Dealing with the distribution of Mononchus nematodes in the Hawaiian Islands together with preliminary observations upon *Mononchus sigmaturus* and *Mononchus brachylaimus* under cultural conditions, and descriptions of eleven species.

Steer "Dry Lot" Fattening Experiment:

The value of molasses and bagasse as a stock feed was again demonstrated in an experiment at one of the plantations, using steers for "dry lot" fattening. The molasses and bagasse were supplemented by an imported protein concentrate.

Frederick A. G. Muir

THE WORK OF DR. FREDERICK A. G. MUIR IN THE BIOLOGICAL CONTROL OF SUGAR CANE INSECTS IN HAWAII

By O. H. Swezey and F. X. Williams

With the death of Dr. Muir in England on May 13, 1931, ended the career of a man who had devoted his best years to the field of biological control as a method of controlling insect pests. Dr. Muir began this work for the Experiment Station of the Hawaiian Sugar Planters' Association in September, 1905. This was when the sugar cane leafhopper, *Perkinsiella saccharicida* Kirk., was still a serious pest in Hawaii. It was also shortly after the introduction of the leafhopper egg-parasites* by Albert Koebele and Dr. R. C. L. Perkins, from Australia and Fiji. These parasites had not yet shown their ability to cope with the enormous numbers of their host. Mr. Koebele had been working for more than ten years on the introduction of beneficial insects into Hawaii and, being in failing health, wished to retire from active foreign work in the tropics. On his return from Fiji he spent but a short time in Honolulu in the summer of 1905, before leaving for California. Mr. Koebele never came to Honolulu again.

To carry on the work in which Mr. Koebele had been so successful since his arrival in Hawaii in 1893, Dr. Muir was engaged and his services on the staff of the Experiment Station, H. S. P. A., commenced September 1, 1905.

Spending but a short time in Honolulu, Dr. Muir's first foreign trip was to Fiji with the primary object of investigating the economic conditions of the leafhopper in cane fields there. This leafhopper was a different species from the cane leafhopper in Hawaii and was found doing no damage to cane, being kept in check by several natural enemies the most important of which were the egg-parasites mentioned above and which had already been introduced into Hawaii. Another parasite found to have economic value was a stylopid, *Elenchus tenuicornis* Perk. Attempts were made to introduce this parasite into Hawaii, but it failed to attack the leafhopper in the cane fields here. Still another parasite found was a dryinid, *Haplogonatopus vitiensis* Perk., which was successfully introduced into Hawaiian cane fields, and for a time was quite a factor in the control of the leafhopper. After a number of years, however, it became scarce and in recent years has been seldom seen.

On this trip a great deal of time was spent in investigating the cane borer, *Rhabdocnemis obscura* (Boisd.), to discover if possible the cause of its decrease there, for Mr. Koebele had reported such a decrease in Fiji since his visit there in 1892. No natural enemies were found that could be considered responsible for this. Some of the planters believed that the introduction of a hard-rind variety of cane was the chief reason for the decrease of the borer. After six months in

* *Paranagrus optabilis* Perk., *P. perforator* Perk., and *Anagrus frequens* Perk., from Australia in 1904; and *Ootetrastichus beatus* Perk., from Fiji in 1905.

Fiji, Dr. Muir returned to Honolulu, where a few months were spent prior to starting off in July, 1906, for the Orient, where cane leafhopper parasites were investigated in south China in the vicinity of Macao, and inland from Canton. Cane leafhoppers there were found well controlled by egg-parasites similar to those in Australia and Fiji, and there were other valuable enemies as well. Only one of these was successfully introduced into Hawaii. This was a large black dryinid, *Pseudogonatopus hospes* Perk., parasitic on adult leafhoppers. It was reared at the Experiment Station and colonies were distributed to the other Islands, but it was only after nine years that it was known to have become established in Hawaiian cane fields. It never became very numerous, but even in recent years with the leafhopper usually scarce this parasite maintains its existence, and an occasional parasitized leafhopper is to be found, usually wherever any leafhoppers occur.

In February, 1907, a brief visit was made to the Federated Malay States where conditions as regards leafhoppers and their enemies were found to be about as in China. A search was begun for the cane borer beetle, which was continued in Java. Dr. Muir arrived at Batavia on March 10, and spent several months in the different sugar cane sections of Java, without finding any evidence of our cane borer beetle, or any direct parasites on related beetles in banana and palm trees.

On July 21, he left Java for a few weeks' search for the borer in Borneo, returning to Batavia in September from which place another start was made in October, 1907. The search for the natural home of the beetle borer was continued in Amboina and Larat where at last this insect was found in sago and pinang palms and in sugar cane. No success was had in finding parasites for several months, however. Finally in January, 1908, a tachinid fly was found attacking the grubs or larvae of this borer. Eight months were then spent at Amboina in studying this parasite and breeding it for shipment to Honolulu; but as the parasite could not survive such a long journey attempts were made to establish a relay station at Hongkong. This station, which was to have been conducted by F. W. Terry, was not successful as the tachinids always died en route. Finally Dr. Muir tried taking living material with him to Hongkong, but the flies all died the day before his arrival. This venture having failed, Dr. Muir left Hongkong in November, 1908, for further explorations, visiting Ceram and Makassar, en route to New Guinea where he landed at Port Moresby in April, 1909. Here for the first time the tachinid parasite, that was breeding so well on the borer grubs in palm trees at Amboina, was found attacking a high percentage of the borer grubs in sugar cane. At once preparations were made for stocking cages with borer-infested cane in which the borers were to be parasitized, and brought to Honolulu. Several months were required for this, and when eventually the cages were in readiness for the long journey, Dr. Muir fell ill with typhoid fever just prior to leaving Port Moresby, New Guinea, so that on arriving at Brisbane, Queensland, he was compelled to go to a hospital where he remained for five weeks. His cages were forwarded to Honolulu, arriving there September 15, 1909. Over 200 of the tachinid flies had matured en route, but lacking the personal care that had been planned for them, all had died before

their arrival in Honolulu. Thus is recorded another failure in the introduction of this parasite.

As soon as he had recovered sufficiently in the Brisbane hospital, Dr. Muir came on to Honolulu for further recuperation, arriving about the end of October, after an absence from Honolulu of three years and three months most of which time was spent in tropical jungles where he was exposed to the dangers from wild animals, venomous snakes and insects, as well as to tropical diseases prevalent in those regions.

At once plans were made for further attempts to introduce this parasite on the cane borer. Dr. Muir left Honolulu, January 8, 1910, on the final endeavor which resulted in the transportation of the living parasite to Honolulu and its establishment in the cane fields of Hawaii. The procedure this time was the establishing of a relay breeding station at Mossman, Queensland, cared for by J. C. Kershaw. In cages here the tachinid was bred from material brought by Dr. Muir from New Guinea. Of the first generation of parasites reared in these cages, a portion was taken in the puparium stage to Fiji, where at Nausori another relay breeding station was established. From the next generation of parasites produced here, living material was brought to Honolulu by Dr. Muir on August 16, 1910. Mr. Kershaw arrived a month later with more material reared in Fiji. From both of these lots there were sufficient adult parasites to allow some to be liberated in a few cane fields, while others were retained for breeding in cages. Altogether, over four years were occupied on this project; from the beginning until living parasites were landed in Honolulu. The results obtained in checking the cane borer after the parasite was established and fully distributed, more than justified the time, effort and expense involved.

Staying a short time, until the breeding of the tachinid was well started, Dr. Muir sailed from Honolulu, October 4, 1910, for a well-earned leave, going to England for a year, and returning to Honolulu, October 11, 1911.

The next large project undertaken by Dr. Muir, was the endeavor to find and introduce natural enemies of the cane root grub, *Anomala orientalis* (Waterhouse), which in 1912 was found established in cane fields in the Pearl Harbor district of Oahu. There was little or no encouragement to be had from previous efforts to control root grubs by natural enemies in other parts of the world. However, after duly considering the situation, Dr. Muir believed that an attempt should be made to control the spread of Anomala in our cane fields by this method. He left Honolulu for Japan, March 28, 1913, that country being the home of *Anomala orientalis*. A number of valuable natural enemies were found working on Anomala there and efforts were made to introduce some of them here, but none ever became established. After about a year in Japan, search was made in Java, Formosa and the Philippines for parasites of closely related species of root grubs that might possibly be utilized against Anomala. The breaking out of the World War disturbed transportation from those regions, and it was found that the Philippines was the most favorable place in which to work and to secure dependable transportation for consignments of parasites. A large number of root-grub enemies were studied in the Philippines, headquarters being established at the College of Agriculture at Los Baños, where every facility for the work was

rendered. Dr. Muir was assisted in the work here by H. T. Osborn and Dr. F. X. Williams, and large quantities of some of the parasites were reared for shipment to Honolulu; many consignments being made during 1915, 1916 and 1917.

Of the numerous parasites of several kinds that were handled, *Scolia manilae* Ashmead, the wasp which parasitizes the Anomala grub, was the only one to become established in our cane fields. It was first found established and breeding on Anomala grubs September 16, 1916. In the four years since its discovery, Anomala had spread over a considerable area of cane land adjacent to Pearl Harbor. As soon as Scolia was found established in one field, assistance was given it in spreading throughout the Anomala-infested area. This was accomplished during the next year, and the wasp proved so efficient that attempts to introduce additional parasites on Anomala were discontinued. This project turned out to be the first successful control of a root grub by means of natural enemies.

During the four years involved in this work, Dr. Muir returned to Honolulu once or twice; on one trip, coming via Formosa, he brought some leafhopper egg-parasites, one of which, *Ootetrastichus formosanus* Timberlake, became established and spread throughout the cane fields of the Islands and was an additional factor in the control of the sugar cane leafhopper. It persists to the present time, even when the leafhopper is normally scarce.

On October 31, 1917, Dr. Muir left for England to engage in war service for his native country in the trying days of the World War. He returned to Honolulu a year later on October 28, 1918. In the meantime he had married Margaret Annie Sharp on April 9, 1918, the daughter of Dr. David Sharp, the noted entomologist who contributed much to the study of Hawaiian insects and to the Fauna Hawaiiensis. Mrs. Muir accompanied Dr. Muir on his return from England, and also on his last trip in search of parasites to Australia, which was begun early the next year.

Although there now existed a fairly satisfactory control of the sugar cane leafhopper by the introduced parasites previously mentioned, nevertheless in a few plantations there were recurrences of leafhopper outbreaks which were of considerable importance. The purpose of Dr. Muir's last trip, May 18, 1919 to June 21, 1920, was to endeavor to find what additional factors controlled the leafhopper in the Queensland cane fields. After considerable research he found that a small bug, *Cyrtorhinus mundulus* Breddin, of the family Miridae lived by sucking the contents of the eggs of the leafhopper. The introduction of this bug into Hawaii was soon accomplished, chiefly from Fiji (where it was known to occur) by C. E. Pemberton the following year September to November, 1920. This bug was reared and colonies distributed for a year, and from thereafter when it became thoroughly established the control of the leafhopper pest in Hawaiian cane fields was practically complete. There have been slight outbreaks occasionally, but the Cyrtorhinus bug was always prompt to find them, and would soon increase to numbers sufficient to regain control. It has been thought that if this bug had been the only leafhopper enemy introduced it might of itself have been able to sufficiently control the leafhopper.

The total results of the major introductions above enumerated have been the saving of millions of dollars to the sugar industry in Hawaii, and the comparative freedom from destructive insect pests in the cane fields.

After returning from the last trip to Australia, Dr. Muir established his home in Honolulu. Much of his time was now devoted to systematic studies in Homoptera, particularly the Fulgoroidea. This is the group which contains the family Delphacidae to which the cane leafhopper belongs. In his travels Dr. Muir made a specialty of studying and collecting sugar cane leafhoppers as well as other related leafhoppers. Many species of these were named and described by him in numerous papers included in the bibliography which follows. He became intensely interested also in the leafhoppers of the forests of Hawaii, and added many species to those already known, these new species of the Hawaiian fauna being published in the *Proceedings of the Hawaiian Entomological Society*. Dr. Muir eventually devoted himself to the study of leafhoppers the world over, and was recognized as a world authority on the leafhoppers of the family Delphacidae. Just before his death he was planning to work up a large collection from South America.

Dr. Muir's health had been undermined by so much time spent in unhealthful tropical jungles, etc., and he went to England at intervals, spending most of the years 1927 and 1928 there. On his return from England, September 12, 1928, arrangements were made for his retirement from active service at the Experiment Station, H. S. P. A. He left Honolulu on November 17, 1928, to make his home in England, and had made preparations for carrying on systematic work there in his favorite family of leafhoppers, which work, however, he was not able to pursue because of his failing health.

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Widths of Cane Rows in Various Sugar Cane Countries

By J. N. P. Webster

Rosenfeld,[1] in a publication of 1920, states:

The question of the best distance to be given between cane rows, in order to allow of the best possible development of the plants consistent with the largest possible yield per acre, is one of much importance and one which has given cause for considerable investigation and discussion. For each kind of plant and soil there should exist a theoretical maximum of the agricultural yield that can be obtained, i.e., each class of soil in each climate is capable, under the best conditions, of producing an exact maximum of well-developed sugar canes, for example, and this maximum can be obtained only under ideal climatic conditions and with perfect cultivation. This maximum also, naturally, can be obtained only by an ideal spacing of the plants, allowing each one to obtain its maximum development; hence, if we have our rows too close together, we shall probably get a great number of inferior plants, and if we have them too far apart we shall probably obtain splendid specimens of sugar cane, but the reduced number of these will fail to give us the tonnage we should have obtained with more plants of normal development.

In Louisiana, Stubbs[2] (according to Rosenfeld's data) has probably done the the earliest experimental work with varying widths of cane rows. The average results of his experiments on one year of plant cane in 1890 and ratoons in the following year are as follows:*

Width of Middles, Ft.	No. of Stalks per Acre	Average Weight of Stalks, Grams	Tons Cane per Acre	Q. R.	Tons Sugar per Acre
3	30,004	1300	45.98	14.48	3.18
4	27,260	1250	40.96	15.58	2.63
5	27,920	1300	43.53	14.33	3.04
6	26,534	1300	40.53	14.96	2.71
7	26,548	1250	39.86	14.05	2.84
8	24,914	1350	39.30	15.45	2.54

He found that up to the time the cane was laid by there was a considerable death of young shoots and this was most noticeable in the close rows in the ratoon crop.

Due to the narrowness of the three-foot and four-foot rows no mechanical cultivation could be given them, but even so, in both the plant and in the ratoon crops the lines spaced 3 ft. apart gave the greater tonnage per acre, followed by the 5-ft. lines.

From the results of the above experiments, the Audubon Sugar Experiment Station adopted the 5-ft. lines for all further experimental work as these were considered most economical for cultural methods.

Stubbs continued the same experiments and the following tables by Rosenfeld, show in part, the cane tonnages obtained:

* For the purpose of convenience in this table and following tables, where necessary, the writer has converted hectares to acres, etc.

TABLE IV

AVERAGE RESULTS IN LOUISIANA FROM FOUR CROPS OF STRIPED CANE

Width of Middles	Tons Cane per Acre	Q. R.	Tons Sugar per Acre
3 ft.	34.42	14.63	2.35
4 ft.	33.44	14.69	2.28
5 ft.	36.92	14.51	2.54
6 ft.	34.29	13.64	2.51
7 ft.	34.19	13.44	2.54
8 ft.	31.90	14.58	2.19

TABLE V

AVERAGE RESULTS IN LOUISIANA FROM THREE CROPS OF PURPLE AND STRIPED CANE

Variety	Width of Middles	Tons Cane per Acre	Q. R.	Tons Sugar per Acre	Average of Two Varieties: Tons Cane per Acre	Q. R.	Tons Sugar per Acre
Purple	3 ft.	31.82	13.95	2.28	33.82	13.36	2.53
Striped	3 "	35.82	12.77	2.81			
Purple	4 "	32.02	13.67	2.34	31.46	13.67	2.30
Striped	4 "	30.90	13.66	2.26			
Purple	5 "	32.14	13.68	2.35	30.60	14.00	2.19
Striped	5 "	29.07	14.32	2.03			

TABLE VI

AVERAGE RESULTS FOR TWO YEARS FROM EXPERIMENTS WITH 5- AND 6-FT. ROWS

Variety	Width of Middles	Tons Cane per Acre	Q. R.	Tons Sugar per Acre	Average of Two Varieties: Tons Cane per Acre	Q. R.	Tons Sugar per Acre
Purple	5 ft.	37.80	13.08	2.89	38.50	13.56	2.84
Striped	5 "	39.19	14.04	2.79			
Purple	6 "	37.52	13.34	2.81	35.61	13.55	2.62
Striped	6 "	33.69	13.75	2.45			

Rosenfeld states:

Table IV shows that for four years the 5-ft. rows again show the maximum of tonnage, while the very fine rows give the smallest yield once more, with the lowest sugar content and largest percentage of glucose of all of the plots. This latter result, which is quite general in the experiments, is diametrically opposed to the general idea; which is to the effect that the purity of wide spaced cane rows will always be superior to that of rows closer together. There is no doubt, however, that sugar cane is a *sociable* plant, and develops best under normal spacing conditions.

In Table V, we see that the average yield of cane increases as the distance between the rows decreases, and once more the best sugar content and purity correspond to the rows with the narrowest middles, although the differences in the contents of the juices are very small.

Table VI gives the average results for two years of further experiments made by Stubbs in 1892 and 1893, with both the purple and striped cane with distances between the rows of 5 and 6 feet, which were the distances most discussed in Louisiana at that time. The cultivation was, it is needless to say, identical in all of the plots, and the

results embrace one crop of plant and one of stubble from the same plantation. Once more the 5-ft. rows show up best in tonnage of cane, and in content of sugar in the juices, and the experiment serves to confirm the opinion that, while it cannot be said at just what distance the cane will give the best results in tonnage and purity, there is at least no advantage in having the middles any wider than is necessary for the easy entrance of cultivation machinery.

Some results of experiments at the Tucuman Sugar Experiment Station are also given by Rosenfeld. These were commenced in 1910 by Prof. R. E. Blouin and continued by the author and later by Dr. W. E. Cross.

The first experiment was started in 1911 and continued in the ratoon crop for 1912.

Table IX, Part II, shows the "Average Results for the Two Years" and is, in part, as follows:

Sub Plat	Width of Middles	Average Weight of Stalks, Grams	Tons Cane per Acre	Q. R.	Tons Sugar per Acre
1	3 ft.	690	14.57	12.7	1.15
2	4 "	730	15.58	12.0	1.30
3	5 "	740	13.62	12.5	1.09
4	6 "	790	15.07	12.8	1.18
5	7 "	680	12.20	12.6	.97
6	8 "	700	10.55	12.6	.84

Rosenfeld states:

The average yields for the two years give the place of honor in production of sugar per hectare to the 4-ft. rows, followed by the 6-ft. ones. Blouin[3] (according to Rosenfeld) concluded from these experiments that, for questions of cultivation, the distance between the rows should not be less than 5 ft., and for questions of yield, more than 6 ft., recommending an average of 5½ ft.

The following table shows the average results of one year of plant cane and three years of ratoons of P. O. J. 36 grown at the Tucuman station using varying widths of lines:

TABLE XI

AVERAGE YIELDS IN P. O. J. 36 EXPERIMENT FOR FOUR YEARS

Width of Middles	Average Weight of Stalks, Grams	Tons Cane per Acre	Q. R.	Tons Sugar per Acre
3 ft.	654	29.87	12.40	2.41
4 "	714	31.24	11.88	2.63
5 "	776	29.98	12.19	2.46
6 "	809	30.04	11.87	2.53
7 "	832	30.55	12.08	2.53
8 "	804	27.48	11.26	2.44

Cross[4] (according to Rosenfeld) concludes:

These results with the P. O. J. 36 cane confirm those already obtained in the Experiment Station with the Creole cane, indicating that approximately the same quantities of cane and sugar per hectare are obtained with rows planted at any distance between 3 and 7 ft. . . . The distance to be selected, therefore, should be *the smallest which will*

permit efficient cultivation of the cane plant as well as stubble, with modern cultivation machinery.

Continuing with experiments at the Tucuman station another series was started in 1916 using P. O. J. 213 and the results compiled for one plant crop and two ratoon crops:

TABLE XII

AVERAGE RESULTS FROM THREE CROPS OF P. O. J. 213 CANE

Distance Between Rows—Ft.	Average Weight of Stalks, Grams	Tons Cane per Acre
3	467	20.98
4	498	21.37
5	495	20.30
6	509	19.47
7	517	18.98
8	543	19.80

Rosenfeld states further:

Once again we see that there is relatively little difference between the average yields of cane per hectare in the distinct sub-plots, the 3 plots with the smaller distances between the rows having given slightly better yields than the 3 with wider middles. The average size of the stalk has also increased again in direct proportion to the distance between the rows. Cross calls attention to the fact that this increase in weight of stalk is due to greater thickness of the canes rather than to increased height.

At the Monte Bello substation, of the Tucuman station, plots were laid out of approximately two and one-half acres each and one plot was devoted to native purple cane and one to native striped cane for each of the series 5, 6, 7 and 8 ft. The average results of the plant and ratoon crops are given here, in part:

TABLE XVI—PART II

Subplot No.	Variety	Width of Middles, Ft.	Ave. Wt. of Stalks, Grams	T.C.P.A.	Q. R.	T.S.P.A.	Ave. of Two Varieties T.C.P.A.
1	Striped	5	1080	27.13	15.59	1.74	26.30
2	Purple	5	935	25.48	17.45	1.46	
3	Striped	6	1030	24.85	13.73	1.81	23.57
4	Purple	6	955	22.27	14.56	1.53	
5	Striped	7	1100	23.77	18.72	1.27	20.94
6	Purple	7	920	18.12	14.16	1.28	
7	Striped	8	1180	20.49	14.23	1.44	18.84
8	Purple	8	900	17.19	12.73	1.35	

To quote Rosenfeld:

The average of the two crops shows a very steady decrease in yield of cane per hectare as the rows were widened, although the average weight of stalk and the juice analyses do not seem to follow any general rule. This experiment, however, very much confirms the conclusions arrived at in former experiments.

In an editorial appearing in the International Sugar Journal for November, 1920,[5] the following criticism of the above paper by Rosenfeld is made:

The paper as a whole appears to be a strong piece of special pleading for the 5-ft. row. It may be that this is insisted on because of local disbelief in its merits, but we have formed the opinion that, considering the great differences in the growth of varieties of cane, the time they are in the ground, and the enormous antitheses in climate and other conditions in the sugar-growing countries of the tropics, a somewhat wide latitude should be allowed as to how much soil should be provided for each cane stool. With this proviso, five feet is a very good distance, and has been more or less adopted in a great many places; and the main consideration in its favor, which is strongly insisted on by the writer of the paper, is that, while not leaving the land bare too long, it is possible to cultivate the soil between the rows with modern tractors or horse- and cattle-drawn implements.

A further criticism is made in that plots in the various experiments have not been replicated, but it is granted that this has been partly guarded against by the number of experiments noted.

In 1922, Rosenfeld[6] published another article on the distance between rows in which he brings up to date, experiments conducted at Tucuman since his previous paper. He arrives at about the same conclusions as in his previous paper.

Cross,[7] at Tucuman, published an interesting article (of which we offer a translation here) on the width of cane rows in which he gives the results of experiments carried on over a number of years with the varieties P. O. J. 36, 213, Kavengire and Zwinga. Concluding his article he says:

Studying the final results of these experiments with the four varieties mentioned, we confirm the conclusions previously formed, which were as follows:

(1). The plant cane in the case of canes P. O. J. 36 and P. O. J. 213, give the greatest rendement of cane and of sugar per hectare with narrower rows (3 ft. to 5 ft.). The ratoons of these varieties, with the plant and ratoons of the varieties Kavengire and Zwinga, give the same rendement of cane and sugar per hectare, whenever the distance between the rows is within the limits of 3 ft. and 8 ft. (3 ft. and 7 ft. for P. O. J. 36).

(2). The cane, in narrower rows, has stalks which are more delicate and of less weight than in rows well apart. Also with narrow rows we obtain more stalks per hectare than in wider rows.

(3). In general, the richness of cane is independent of the width of rows.

Continuing with his discussion Cross takes up the economic factors concerned with the width of rows:

From the foregoing results then, what is the best distance to plant cane? In the first place, we see, practically the same rendement of cane and sugar per hectare is obtained from all distances between 3 and 8 ft. (7 ft. for P. O. J. 36). . . . The selection of the distance between the rows will depend, therefore, on the economic factor; we should select the distance which will result in the cheapest production of cane.

After this point of view of the economic production the very narrow rows are not convenient for the following reasons: 1. The cost of planting the cane per hectare is augmented by the greater number of rows and the greater quantity of cane necessary for planting, etc. 2. With narrow widths it is necessary to cultivate the cane only with a shovel, because agricultural machinery is unable to get between them. The cultivation by spade is much more costly than cultivation by machinery. 3. The cane produces stalks more delicate and more numerous and makes harvesting more costly. Cane planted at the greater limits of distance, on the other hand, will close in late in the growing season, thus necessitating a greater number of cultivations than would be required in canes planted in narrower rows. We should not forget, however, that the greater cost of production of cane is that which has to do with the making of furrows, and for this reason,

within certain limits the cost of production per hectare will be less as we reduce the number of rows.

At Tucuman, the Reynoso system of Java was compared with the ordinary method of row planting for a period of 6 years, but from the results Cross[8] concluded that this system was not profitable, except in a few cases, because of its cost.

In other sugar producing countries of the world we find the width of rows varying from 4 to 6 ft. In Fiji[9] the rows vary from 5 ft. to 6 ft., the wider distance to enable tractor work in young cane. Furrows in Peru [10, 40] are spaced about 4½ feet apart.

In Mauritius [11, 12], rows are 4 to 4½ ft. apart and cane is planted in holes, spaced 3 ft. apart, made in the rows. Spacing in South Africa [13, 14, 27] varies from 4 ft. to 6 ft., but the average as a rule is 5 ft. In Queensland[15], the width of row apparently depends on the type of cane, "varying from 4 ft. 6 inches for thin erect canes to 6 ft. for thicker canes. . . . The greater part of the cane planting is in 5 ft. rows."

The width between rows in Northern India [16] is from 1 ft. 6 inches to 2 ft. For other sections of India, Sayer [17, 18] states:

> As a result of the experience gained so far, it may be definitely stated that the optimum distance between rows of cane in this part should be 3 ft. for medium thick canes like Co. 213 and 210, while it should be 2 ft. 6 inches for thin canes. This enables intercultural operations to be performed with ease and also helps secure a good crop.

In St. Croix[20], rows are 4¾ or 5 ft. apart, and in some cases the seed pieces are spaced in the lines. The area occupied by each seed piece is known as a hill. Some work has been done with spacing of lines and seed pieces within the lines, and the following table of results is taken from a recent publication [36]:

Plot No.	Distance Between Rows—Ft.	Distance Between Hills—Ft.	Yield per Acre of Plant Cane Tons	First Ratoon Tons	Second Ratoons Tons	Average Tons
1	3.00	2.0	18.67	9.42	23.21	17.10
2	3.00	2.5	11.60	7.85	19.58	13.03
3	3.00	3.0	14.61	8.73	20.07	14.47
1	4.00	2.0	14.97	6.80	17.82	13.03
2	4.00	2.5	13.37	5.86	17.27	12.17
3	4.00	3.0	12.88	6.85	18.24	12.66
1	4.50	2.0	Data lost	6.17	14.23	10.21
2	4.50	2.5	"	5.91	12.12	9.02
3	4.50	3.0	12.46	5.27	15.29	10.99
1	5.00	2.0	13.65	5.70	18.32	12.65
2	5.00	2.5	14.96	4.40	11.91	10.42
3	5.00	3.0	17.28	3.10	8.50	9.63

No comments on the above results are made in the publication, but it is interesting to note that higher yields are obtained with 3-ft. rows and with seed pieces 2, 2.5 and 3 ft. apart. Rows spaced 3 ft. and seed pieces spaced 2 ft. in the line gave the highest yields in the three crops.

In Trinidad [19], the distance between rows is 5 ft. Depending on the fertility

of the soil, the distance between rows in Costa Rica [21] varies from 5½ to 8¼ ft., while in Brazil [22, 35] rows are mostly 1.2 to 1.5 meters apart, or 4 to 5 ft.

Concerning Formosa, Rosenfeld [23] has the following statement:

The planting is usually done in rows about 42 inches apart, in quite a lot of cases a modified Reynoso system, as in Java, being used, though shallower planting and flatter cultivation is more general. Occasionally one finds double row plantings, i.e., two rows about 18 inches apart on one bank and then a middle about 5 ft. wide to the next bank. In this case cultivation is carried on only on the outsides of the double rows, no attempt being made to cultivate the narrow middles.

Honduras [24] plants its cane in rows usually spaced at 6½ ft.

Concerning the distance between trenches in Java, van Deventer [25] states:

The distance between the planting furrows (trenches) which rarely exceeds 5 feet, decreases to 3 feet on less fertile lands. Smaller distances are not used for crop cane (but occasionally for nursery cane). . . .*

As long as the planting distance is wider than the optimum distance the rendement is little influenced. When, however, very close planting is practiced a lower rendement is obtained than with more distant planting. Besides, the percentage of recumbency increases with closer planting.

The most usual distance between the furrows is 4 ft., but all distances ranging between 3 and 5 ft. are frequently seen, especially in East Java many plantations plant closer than 4 ft., and the same applies to the fields in Central and West Java. At present only a few plantations plant at distances of 4½ to 5 ft. from center to center. . . .

Periodically, experiments with greater planting distances are still being made at different places, some of them reach 8 ft. with double rows, but these attempts are usually abandoned speedily because the sugar yield in double rows is considerably less than in single ones.

H. Atherton Lee [26] in a report says:

Our experiments here in the Philippines very carefully done, have shown us that better yields per hectare are obtained if the cane rows are 1 meter apart (40 inches) than if 1.25 meters (50 inches) or 1.66 meters (66 inches). These results as to the narrower distance between rows giving higher yields per hectare have been fully supported by the studies in Java, and they have gone much further with the subject than we have. The data from more than 1000 experiments shown me by Mr. Demandt, chief of the field service, yield the following conclusions:

1. That the important factor is not so much width between cane rows, or distance between seed pieces, but rather the number of cane stalks which come to maturity per hectare.

2. At this point Mr. Lee states that a variety has an optimum number of stalks per hectare up to a certain point, above which, although cane tonnage will increase, purities will be lowered.

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* With the Reynoso system of trenches as used in Java, consideration should be given the fact that the narrower the trenches the greater is the aeration, considering the area as a whole, of not only the soil removed from the trenches, but, also the wall of soil separating the trenches.

Previous to the crop of cane one to two crops of rice are grown and as these crops require water for their development the land is much water-logged. Consequently any aeration of the soil should do much to enhance its condition both physically and chemically. With the trenches closer together a greater proportion of the total area is spaded, and exposed to aeration, which may account, in part, for the higher yields obtained from closer spacing. (J. N. P. W.)

3. Mr. Demandt's work then showed that by narrowing the distance between cane rows the number of stalks per hectare was easily increased.

4. On the contrary, however, lessening the distance between seed pieces did not have much effect on the number of stalks per hectare.

During the year 1928, Demandt [39] has shown that of a total of 180 experiments with distances between furrows, 157 were with P. O. J. 2878, 8 with D. I. 52, 6 with E. K. 28, and 9 with 5 other varieties.

Further on he states:

Of the 152 different experiments with 218 distinct comparisons 3 ft. is found as the closest distance 33 times, 3½ ft. 108 times and 4 ft. 11 times. The widest distance that was investigated was 5 ft. and it occurred 10 times in these experiments.

In the following table he shows, by percentage, the distribution of the comparisons for various years:

Crop	In Favor of Closer Distance	No Difference	In Favor of Wider Distance
1924	52%	29%	19%
1925	51%	32%	17%
1926	37%	55%	8%
1927	48%	37%	15%
1928	50%	32%	18%

In this respect, the relations have not changed. It has to be considered, however, that this applies only if always about the same number of different distances are being compared. During the last two crops the distribution of the distances examined was the following:

DISTANCES EXAMINED

Crop	3 Ft.	3½ Ft.	4 Ft.	4½ Ft.	5 Ft.	6 Ft.	Remarks
1927	5%	29%	44%	13%	8%	1%	Of all comparisons
1928	10%	41%	41%	5%	3%	...	"

It can be seen immediately that as compared with crop 1927, a shifting has taken place toward the closer distances. Due to the fact that the relations in favor of narrower or closer distances have remained about the same for the two years, it is implied that also in this respect a shifting toward the closer distances is taking place.

The following three graphs from a publication by Demandt [28] are interesting in that they show the relation of the cane and sugar yields to the number of stalks of 3 varieties grown in Java.

From Fig. 1 we see that better juices are obtained up to about 13,500 stalks per acre, after which there is a gradual decline. The cane yield increases steadily up to about 16,500 stalks per acre and then remains constant, while the sugar yield also increases steadily up to 15,500 stalks per acre and then declines due to poorer juices.

The statement is made that the decline in juices is more marked from closer spacing of seed pieces in the line than from closer lines, and also that a higher maximum yield is obtainable by closer lines than by closer spacing of seed pieces.

With D. I. 52, Fig. 2, we find a very slight improvement in juices up to about 16,500 stalks per acre and then a gradual decline. The cane yield increases decidedly up to about 21,000 stalks per acre and then very slowly up to about 25,000 stalks

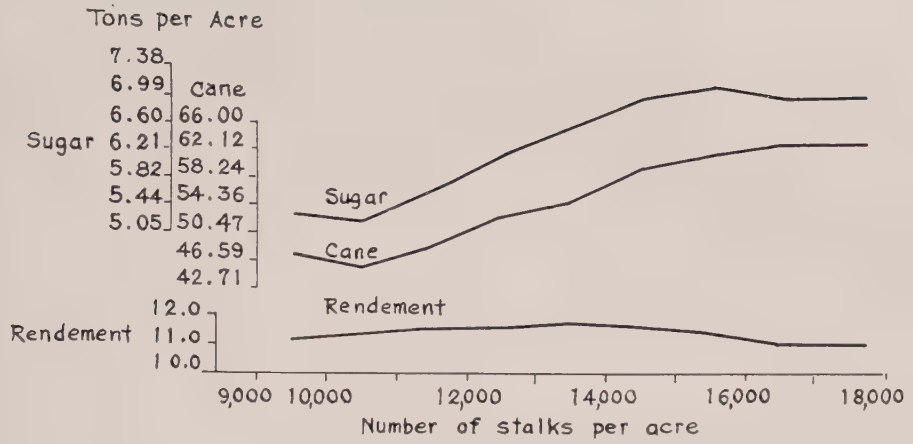

Fig. 1. Average results of 360 spacing experiments conducted with the variety E. K. 28 from 1921 to 1928.

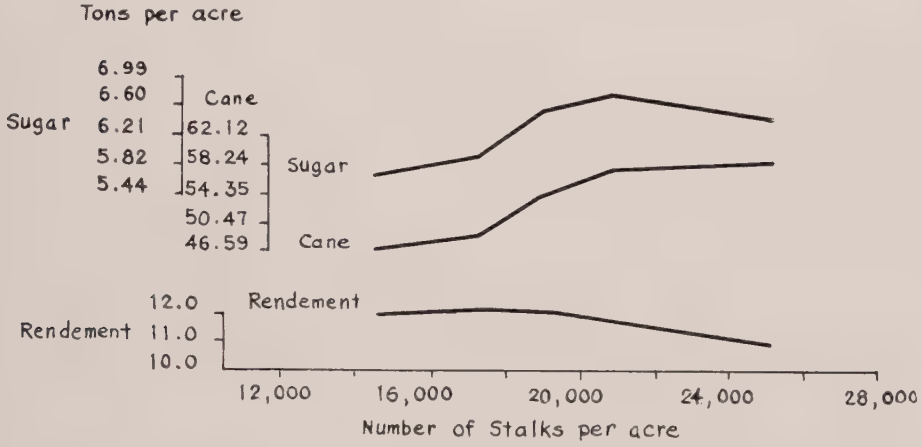

Fig. 2. Average results of 94 spacing experiments conducted with the variety D. I. 52 from 1921 to 1928.

per acre, which is the largest number of stalks recorded. The sugar yield also rises decidedly up to about 21,000 stalks per acre and then there is a decline caused by the poorer juices.

With the juices of P. O. J. 2878, Fig. 3, we find a slightly different condition, for instead of a rise in sucrose content then a gradual decline, as in E. K. 28 and D. I. 52, with increasing numbers of stalks per acre there is a gradual decline. Cane yield increases steadily with increasing stalk numbers and the sugar yield does likewise. The latter because the increase in cane yield more than offsets the decrease in rendement.

Dillewijn [29] by means of a graph, Fig. 4, shows the optimum spacing between lines in the spacing experiments of 1928 and 1929. There were 222 experiments in 1929.

From this graph it can be seen that in 1928 the optimum spacing in 45 and 43 per cent of the total comparisons was found to be 3½ ft. and 4 ft. respectively;

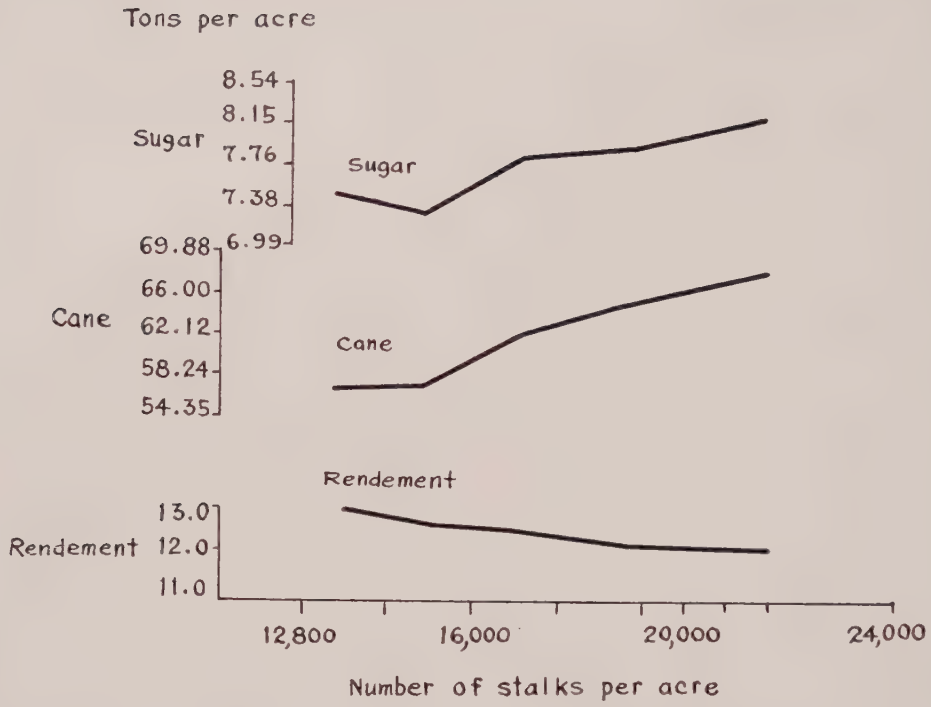

Fig. 3. Average results of 1099 spacing experiments with the variety P. O. J. 2878 from 1927 to 1929.

while in 1929 the optimum spacing was found to be almost 60 per cent for 3½-ft. rows and about 25 per cent for 4-ft. rows.

In the Philippines some experiments were carried out by Locsin [30] to determine what the distance between rows in the Victorias District should be. He found that the narrow rows gave a greater yield of cane and of sugar per acre as shown by the following tables:

I. GASTON HACIENDA

Distance	Plant Tons per Acre		Ratoons Tons per Acre	
	Cane	Sugar	Cane	Sugar
3 ft.	30.18	3.15	24.59	2.89
4 ft.	28.62	2.79	22.63	2.77
5 ft.	29.23	2.82	16.22	1.98

II. MIGUEL HACIENDA

3 ft.	22.00	3.02	24.82	3.58
4 ft.	18.67	2.65	22.09	3.14
5 ft.	17.82	2.45	20.81	2.97

Mr. Lee [31], in his annual report for 1929, gives the results of 2 experiments in width of rows which were very carefully laid out and each had a large number of replications. One was carried on in La Carlota District and the other in the Hawaiian-Philippine Company District.

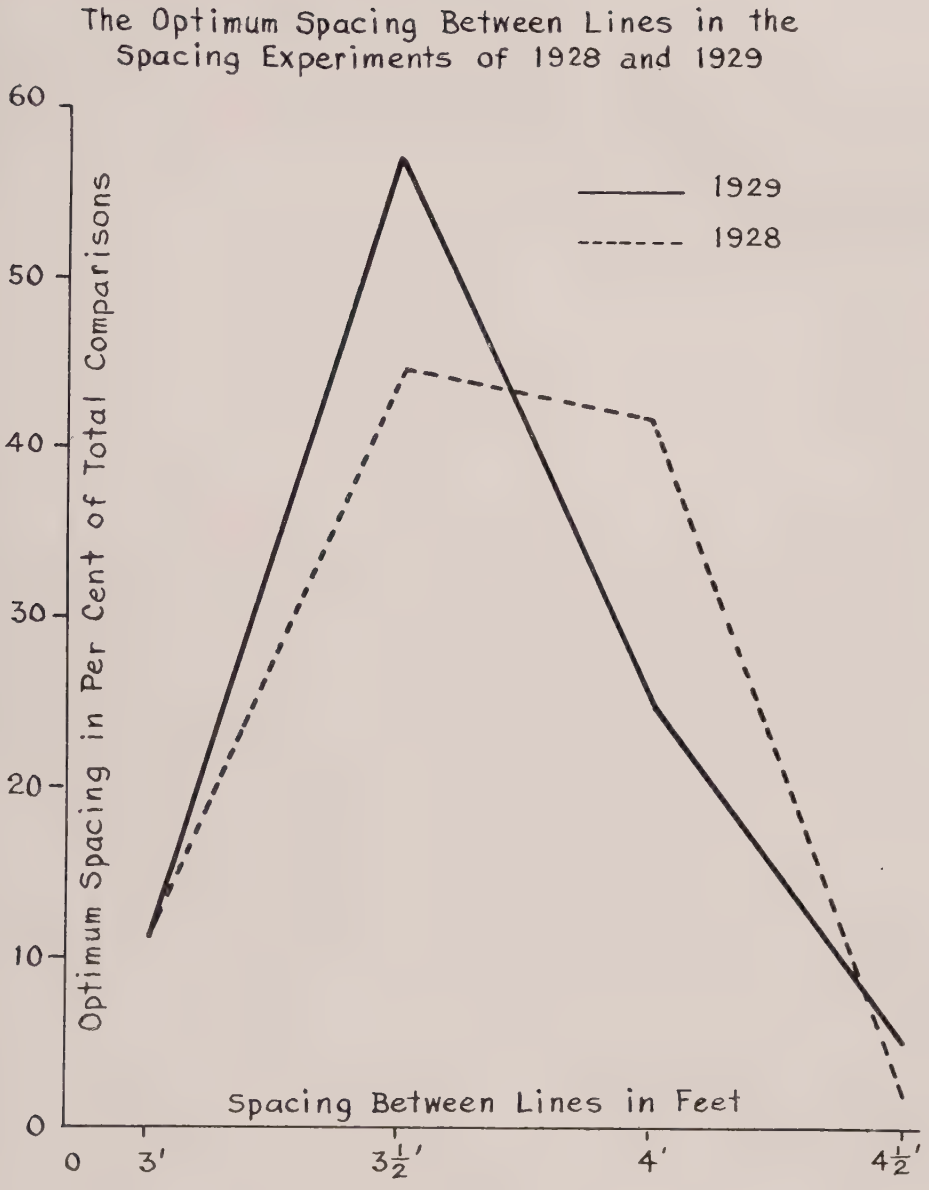

Fig. 4.

The results of the two experiments are given here in part:

LA CARLOTA

No. of Replications	Distance Between Cane Rows	Tons per Acre	
		Cane	Sugar
20	3⅓ ft.	17.05	2.63
20	4⅙ ft.	16.55	2.55
20	5½ ft.	14.42	2.22

HAWAIIAN-PHILIPPINE COMPANY

No. of Replications	Distance Between Cane Rows	Tons per Acre	
		Cane	Sugar
19	3⅓ ft.	29.57	3.83
19	4⅙ ft.	28.14	3.80
19	4⅔ ft.	26.21	3.56
19	5½ ft.	25.05	3.54

From the results of the above experiments, Mr. Lee concludes:

These results are in close agreement with the results at La Carlota, pointing to increased yields with closer spacing. . . . It is interesting to note, however, that the width between rows seemed to have no influence on the quality of the juices in the experiment at La Carlota, while there is tangible definite improvement in the quality of the juices with greater spaces between rows in the Maquina experiment. The explanation may lie in the greater yields and hence more crowded condition of the cane at maturity in the Maquina experiment.

In Cuba [32, 33] the method of planting depends more or less upon the kind of land being planted. Where cultivation is possible rows are usually 6 ft. apart. Rows in Porto Rico [34] are spaced at distances from 5 ft. to 6 ft.

In Hawaii, the earliest work on the optimum distance of spacing cane rows is found in a publication by Blouin [37] wherein he gives the results of his experiments. Cultivation, fertilization and irrigation were the same to all plots. No mention is made as to the number of replications nor the number of rows used for each plot.

His results summarized are as follows:

Width of Rows	Per Cent of Sucrose in Cane	Tons per Acre	
		Cane	Sugar
4 ft.	15.09	101.82	15.37
5 ft.	14.33	135.01	19.35
6 ft.	13.14	108.36	14.24
8 ft.	12.62	98.37	12.41

Here the 5-ft. rows show the highest yields in cane and in sugar and Blouin concludes:

Most of the cane rows on the Islands are 5 ft. and these experiments show very forcibly that this is the most economic and advantageous distance to plant. . . .

Local conditions will have to be considered in the absolute determining of the distances between the rows, but every effort should be made to have them conform as nearly as possible to the 5 ft. rows.

In 1914, Experiment J [38] at Waipio was laid out, "To study the varietal differences of Lahaina, Yellow Caledonia and D 1135 in connection with different widths of rows." Four replications of each variety and each width of row were used, each row being spaced 4½, 5, 5½ and 6 ft. We are thus dealing with both a variety test and a width of row experiment.

The results of the experiment were as follows:

	4′ 6″		5′ 0″		5′ 6″		6′ 0″	
Variety	Cane	Sugar	Cane	Sugar	Cane	Sugar	Cane	Sugar
Y. C.	74.2	9.69	82.9	10.17	66.9	8.66	76.4	9.95
D 1135	87.6	11.39	94.2	12.16	85.7	10.96	91.7	11.96
Lahaina	71.9	10.40	74.9	10.72	73.5	10.72	70.9	10.33
Averages	77.9	10.49	84.0	11.02	75.4	10.12	79.7	10.75

Commenting on the above results the statement is made:

Whereas the average results of this experiment show considerable variation with rows of different widths, at the same time this variation is inconsistent and permits of no very definite conclusion that anything is to be gained by adopting a given width of row within the limits of those under test.

At Kilauea Sugar Plantation Company an experiment (No. 39, Crop 1923) comparing 3-, 4- and 5-ft. lines was harvested with the following results:

Treatment	Tons Cane per Acre
3 ft. lines	21.2
4 "	17.2
5 "	16.8

There were 4 replications each of the 3- and 4-foot lines and 3 replications of the 5-foot lines. Each plot consisted of 12 lines and the cane was plant Badila. There was a gain of practically 4½ tons of cane in favor of the 3-ft. lines over the 5-ft., but whether or not this gain was sufficient to offset increased costs is doubtful.

For the crop of 1932 there is in progress an experiment (Experiment 56M) at Hilo Sugar Company comparing 3-, 4- and 5-ft. rows. The cane is Yellow Caledonia plant at an elevation of 750 ft. There are 3 replications of each of the 4- and 5-ft. plots and 4 replications of the 3-ft. plots.

At Waipio Substation, Experiment B for the 1932 crop compares 2½ ft. spacing of rows with the standard 5 ft. The cane is H 109 and there are 12 replications of each of the two treatments. Another experiment (Experiment J) also for the 1932 crop compares our present lines, 5 ft. wide, with a paddy 10 ft. wide in which 3 lines of cane are planted. There are a total of 14 replications, 7 with H 109 and 7 with P. O. J. 2878.

Throughout the literature we find that in the majority of cases greater yields are obtained when cane is planted in narrow rows, yet why do so few countries adopt narrow rows as a standard?

There are a great many problems to be considered when rows are made narrow. Rosenfeld states: "For each kind of plant and soil there should exist a theoretical maximum of the agricultural yield that can be obtained." This is true, but even so we have to consider the increased costs due to narrower rows.

For instance, taking an average length of line as 35 ft. we have the following numbers of lines per acre at different widths:

Rows	3 ft. apart	415 rows	per acre
"	4 ft. "	311	"
"	5 ft. "	249	"

Decreasing the width of rows from 5 ft. to 3 ft. gives 166 more lines per acre and naturally these extra lines increase costs all the way from the amount of seed needed for planting up to shipping a greater tonnage of sugar.

Then too, practically all of the experimental results shown above have been with one-year crops, whereas here in Hawaii our crops average almost two years and results might be quite different.

It seems to the writer that where experiments in width of rows are installed,

careful cost comparisons should be kept in order to determine whether or not the increased tonnage is really as profitable as might appear.

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Climate in Relation to Sugar Production

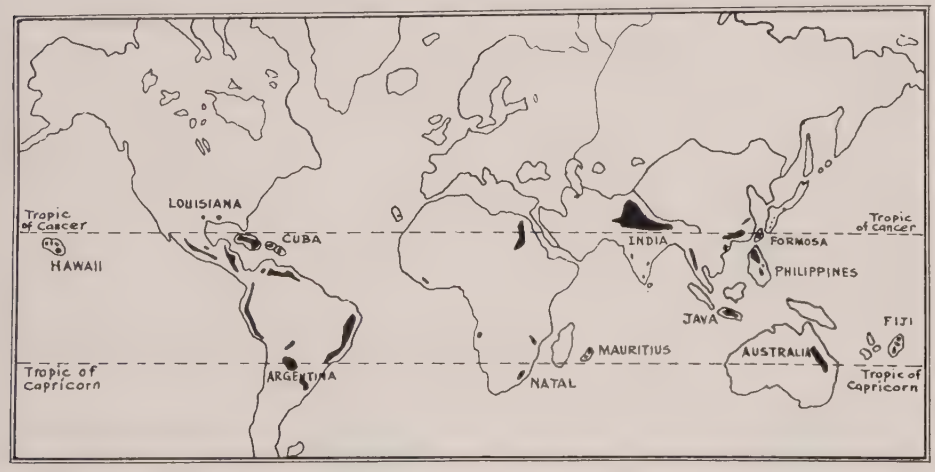
By U. K. Das

Outline

(1). Climate and sugar cane regions.
(2). Weather elements and cane growth.
(3). Weather and sugar yield in Hawaii.
(4). Total warmth and sugar yield at Pepeekeo.
(5). Weather conditions and juices.
(6). Weather and sugar yield in other countries.
(7). Conclusion.

Climate and Sugar Cane Regions

Looking at the world map we find that the principal sugar cane countries lie within the tropics. Louisiana and Argentina on the border of the tropics but outside of it, mark the extreme limits of the sugar cane region. The warm climate of the tropics is thus seen to be essential to profitable cane growing. In fact had it not been for our equable and subtropical climate, the cane would grow faster, ripen in less time and we would have been able to raise a crop in about one year's time like they do in Cuba and Java.



WORLD MAP SHOWING IMPORTANT SUGAR CANE REGIONS

After K. K. Rao, Agricultural Journal of India.

Fig. 1. Sugar cane flourishes best in a tropical climate.

Weather Elements and Cane Growth

Having thus seen that, broadly speaking, climate is the most important factor in determining the suitability of any locality for growing sugar cane, and having

found ourselves where we are, what immediately concerns us is not the long range climate but that phase of it which we experience from day to day, namely, the weather.

Sunlight, warmth, rainfall, humidity, wind—all these are the phenomena of weather, and we all know that these do influence our sugar cane crop as they do any other crop. We all speak of drought reducing our yield, cool weather improving our juices. But strange as it may appear, most of us when we think of past weather think of only the harmful ones, the benign influences of good weather are not often recognized or remembered. As that eminent English weather-man, Sir Napier Shaw once said, "As of other benefactors, it may be said of the passing years:

'The evil that they do lives after them,
The good is oft interred with their bones.'"

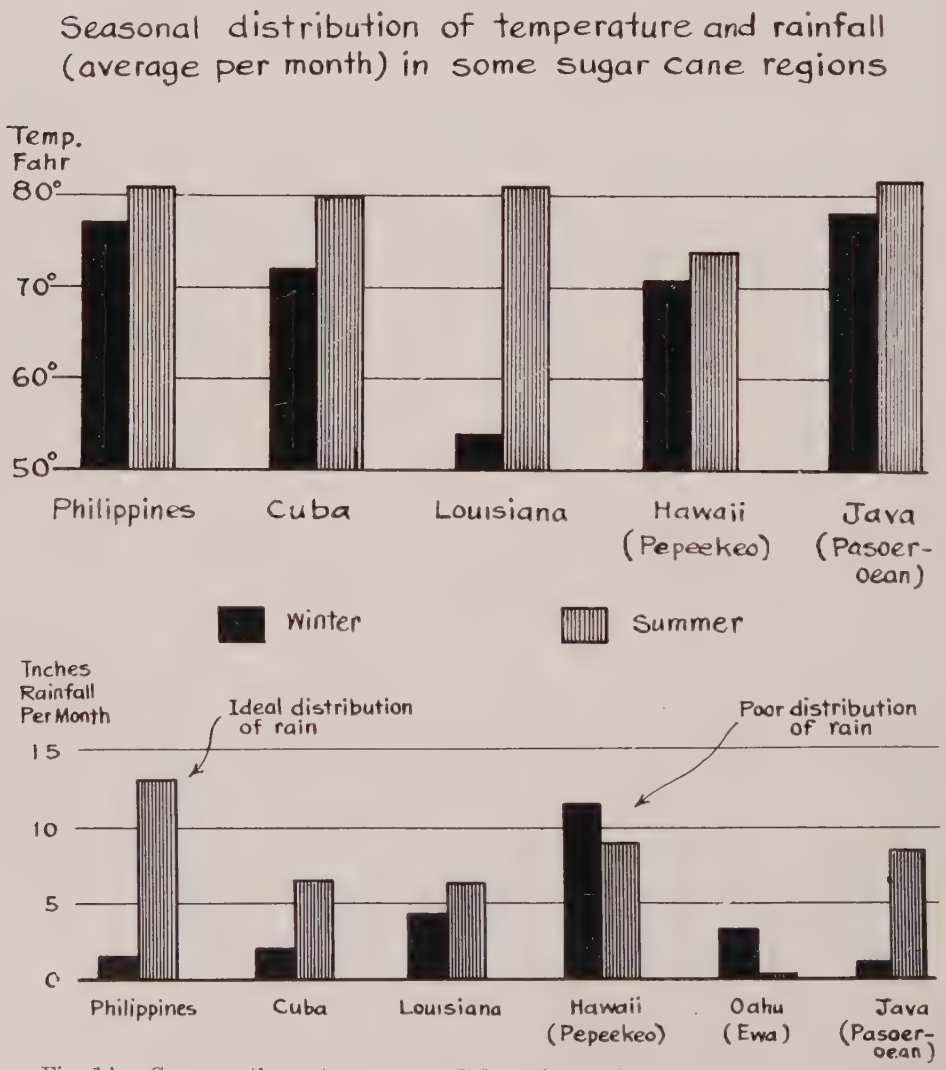


Fig. 1A. Compare the wet summer and dry winter of the Philippines as against the dry summer and wet winter of Hawaii.

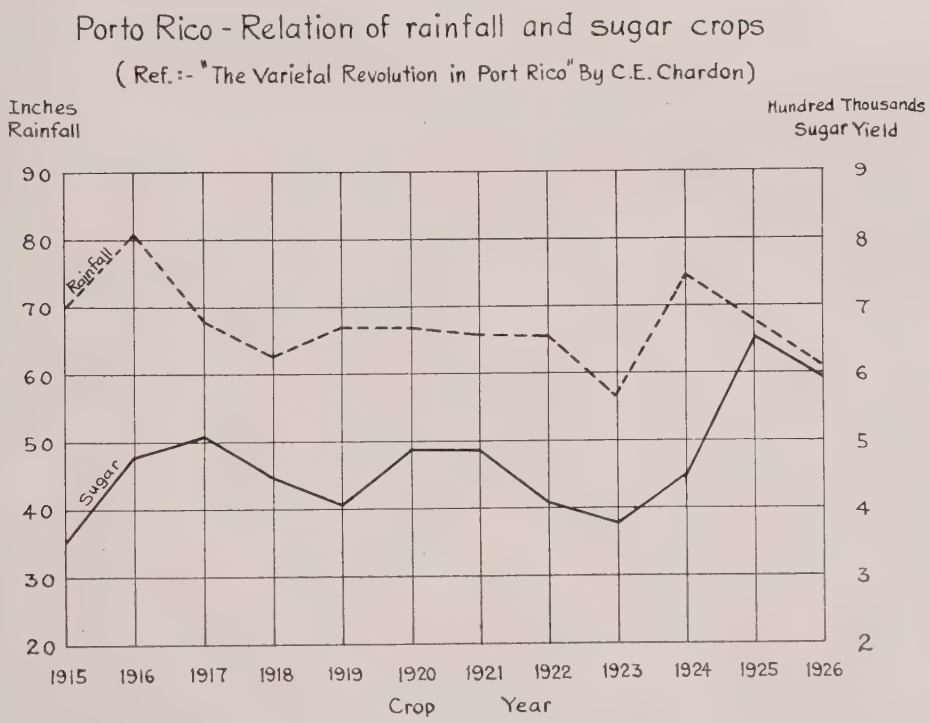


Fig. 1B. Note the close correlation between rainfall and sugar yield in Porto Rico.

What we need, therefore, is to organize our knowledge of the influence of weather on sugar cane, so that not only shall we be able to put down losses to bad weather but also we shall be able to estimate the increased yields due to good weather.

How do these weather conditions affect a crop of sugar cane? First, let us see what we need to grow a successful crop. We need (1) time, (2) light, (3) warmth, (4) moisture, in the soil and in the air, (5) plant food. Of these we can control time and plant food and we can partially control, or better, we can supplement the deficiency of moisture, at least on irrigated areas. Of the other factors, over which we have no control, we may have enough or not enough for our crop.

Sugar cane is a tropical plant and it requires plenty of moisture and warmth for good growth. We know, for instance, that cane grows so much more in summer than in winter, that is, the increased temperature and light in summer increases the rate of growth. We also know that cane suffers if there is not enough moisture in the soil, especially in summer when the rate of growth is higher. To obtain a good crop we should, therefore, have light, warmth, moisture, etc., and each at the right time and in the right quantity. That is just where the weather affects us. Though it is true that the average temperature or average rainfall from year to year may not show great fluctuations, the seasonal temperature and rainfall may. That is, one year we may have a very hot summer and little rain, another year a cool summer and too much rain, and still another when we have both high temperature and high rainfall. We can easily see then, that in the last case growing conditions would be ideal and as a result we would expect to harvest a bigger crop.

A good deal of work has been done in recent years both here and abroad in organizing such loose observations and systematizing the relationship between weather conditions and crop yield. Here, we have studied the annual fluctuation in the yield from year to year in the case of an unirrigated plantation, the Pepeekeo Sugar Co. and an irrigated plantation, the Ewa Plantation Co. We know that the tremendous variations in the yield from one year to another could not possibly be due to anything that we could or could not have done, for our methods and cultural practices do not change so abruptly from year to year. True we may have two tons more sugar per acre in 1925 as compared with 1910 because of improved methods, but there is no reason why we should have a ton more sugar in 1915 than in 1913, 1914, 1916 or 1917. These big variations, we can reasonably believe, were brought about by factors beyond our control.

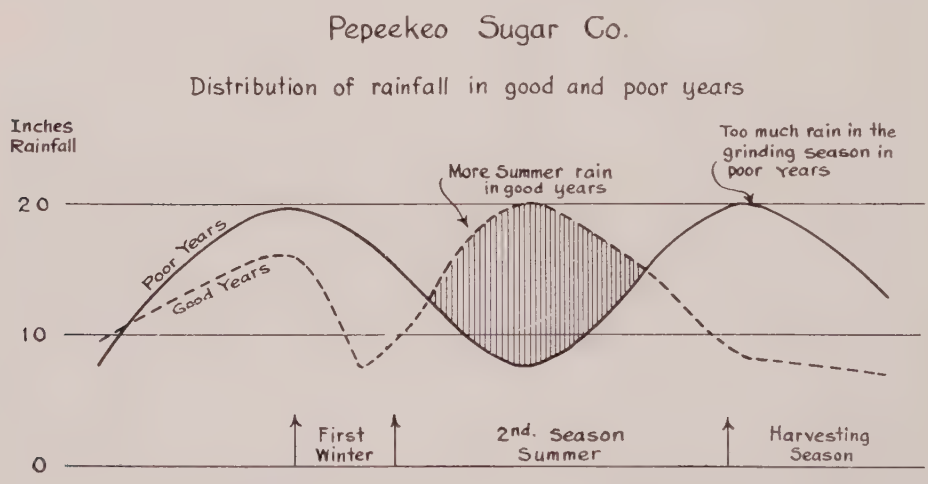


Fig. 2. Rainfall was ideally distributed in the case of high yield years; poor crops were harvested when rainfall was insufficient in the growing season and overabundant in the harvesting period.

In the case of Pepeekeo, we picked out some years that showed a big increase in yield and also some that showed a big decrease compared with the neighboring years. We then started to find out the average condition of warmth and also moisture for the good and the bad years. From Fig. 2, we see that the good years had the right amount of water in the right season, that is, more water in the summer when the cane is growing vigorously and less water in the harvesting period when the canes need to be ripened. From Fig. 3, we see that both in the first season, and second season, the good years had more warmth than the bad years. In other words, what we had often suspected to be the cause of our decreased yields, is found on analysis to be entirely correct. In such years we had drought when we needed water and too much rain when we wanted to ripen our cane and did not need any. The same holds true, more or less, in the case of the irrigated plantation we have studied, with the only difference that in this case the quantity of irrigation water, not so much rainfall, is the important factor.

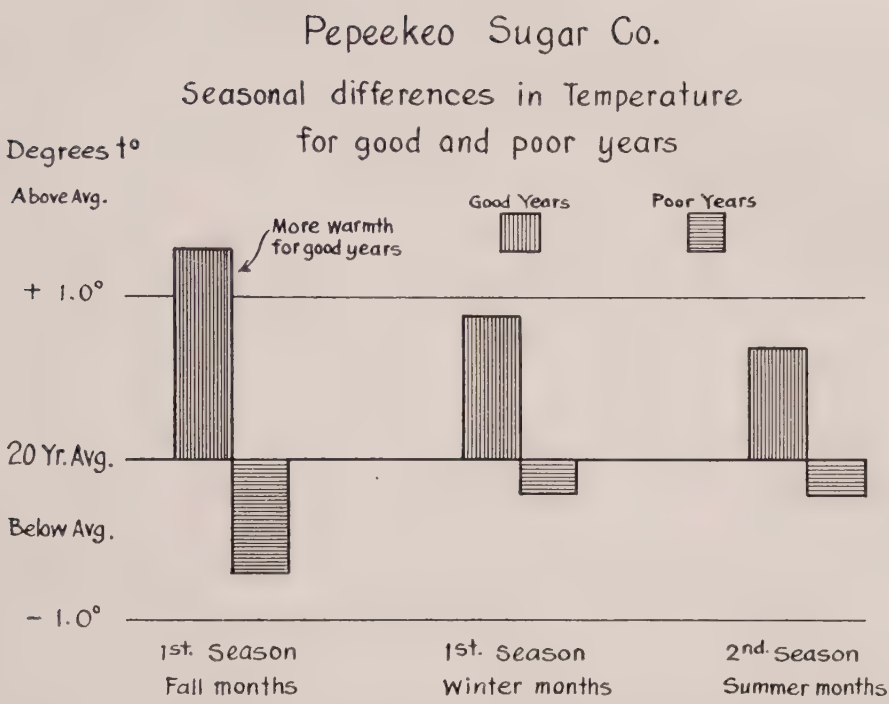


Fig. 3. Warm growing weather reflects itself in higher yields. Temperature was consistently above normal in the high yield years and consistently below normal in the poor years.

Total Warmth and Sugar Yield at Pepeekeo

In the case of Pepeekeo (and what we have to say of Pepeekeo holds true of the island of Hawaii as a whole) we also made another significant discovery, that our periods of high yield and low yield showed a definite relationship to conditions of warmth. It is easy to visualize and gauge the efficacy of one inch of rainfall but not so one degree of temperature. One week we have a temperature of 78° and the next, perhaps 79°. Most of us would not notice the difference, if we were not told so; but the plants being more sensitive know the difference right away and they respond to such differences and it really makes a big difference in the growth of a plant. Let us figure it out this way. We know cane does not make any growth in Louisiana in winter when the mean temperature is 55° F. That means that in the case of sugar cane, only a temperature of over 55° is effective. A temperature of 78° means 23° of effective temperature, and 79° is 24° effective. That gives us a relation of 23 to 24 or 100 to 104. If sugar cane grew exactly in proportion to the warmth it receives, (and there are evidences that it does so to an extent) then, as a result of this one degree difference, and other things being equal, we would expect to get a 4 per cent better growth. Most probably, the actual difference would be greater because we have reasons to believe that the lower limit of growth is not 55°, very likely it is over 60°. However, what we started to make out is that an imperceptible difference in warmth may make an appreciable difference in cane growth. Now if we collect for every

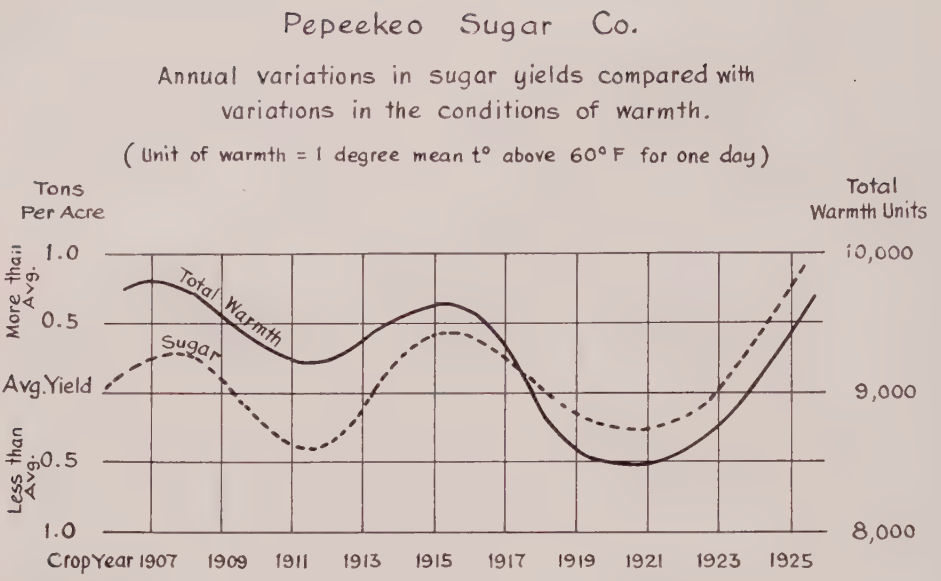


Fig. 4. The periods of low and high yield at Pepeekeo coincide with periods of low and high temperature. Temperature above the average is, therefore, essential to high production.

crop year, all such degrees of temperature above 60°, and also count the number of days when these differences obtained, we find, what we may call, the total quantity of effective warmth for any given year.

In Fig. 4, we have charted the total warmth thus calculated against the sugar yield of the corresponding year. We have used free hand curves just to show the tendencies; the individual years do not always show corresponding fluctuations due no doubt to the influence of other factors such as moisture, plant food, etc. Fig. 4 shows that the periods of high and low yields are definitely associated with conditions of warmth. We are growing a tropical plant in a subtropical climate and it should not, therefore, surprise us to find that warmth has such a big influence. It does not mean that other factors such as our methods and cultural practices are of no importance, it means only that together with others, the condition of warmth is also a factor in production that should be reckoned with.

Weather Conditions and Juices

Our knowledge of the influence of weather conditions on the physiological processes of cane ripening is still meager. In general, we may safely assume that whatever affects the processes of growth also affects the processes of ripening—though the effect may not be of the same nature or degree. Recent studies indicate that good juices are generally obtained when the days are bright and warm and the nights cool during the growing period of the crop and particularly in the fall months before harvest. Excessive rainfall during or immediately preceding harvest is detrimental.

Fig. 5 shows graphically what we believe to be the effect of moisture and warmth during and immediately preceding harvesting seasons. But it must be

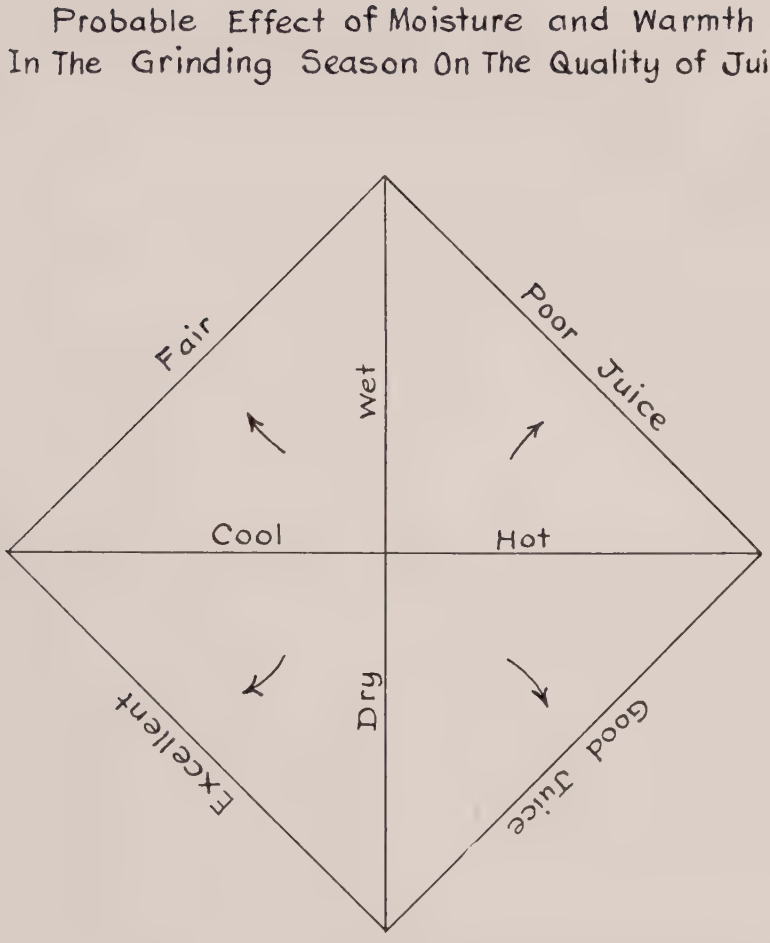


Fig. 5. The above is only a part of the picture. Weather in the grinding season alone does not determine the quality of juice. The conditions of the growing season also have influence.

borne in mind that conditions during the grinding season alone cannot account for the good or poor juices; the conditions of weather and field culture under which a crop is grown have as much, if not greater, effect on the quality of juice.

Weather and Sugar Yield in Other Countries

The same kind of relationship between warmth, moisture and sugar yield has been found to exist in Java, Mauritius, Philippines and Louisiana. Everywhere, it has been discovered that it is not so much the annual amount of warmth or rainfall that counts but the seasonal amount and more precisely the quantity of warmth and moisture that a sugar cane crop receives at a particular period of its growth. These periods have been called the critical periods and it has been shown that if the plants do not have the optimum requirements at these critical periods they are checked permanently. In these islands also, we have such periods and

most of the plantation men have some ideas about these; but we need to know them more definitely so as to be able to follow the progress of a crop more closely.

Conclusion

Summarizing, we can say, climate is of great importance; firstly, it makes a country a good or a bad sugar cane country, and secondly, its temporary phases, otherwise called the weather, materially influence our yields from year to year.

All over the world, we have just begun this absorbing study of the relation of climate to sugar production. We need to know more, and more definitely about the influence of such factors on growth as sunlight, maximum and minimum temperature, humidity, etc. The preliminary studies have already given us a better knowledge of the relationships which we had often suspected but could not always prove.

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The Significance of Climatic Differences Among the Sugar Plantations of Hawaii

By U. K. Das

In comparing one plantation with another, we usually take into consideration the differences in soil types and in the amount of rainfall, or of water supply if they are irrigated plantations; but hardly ever do we give much thought to the differences in the climatic conditions of the two places. This is perhaps the result of a belief that climatic conditions cannot vary to any extent within the narrow geographical limits of these Islands. Our belief is far from being well founded; for recent studies of the relation of weather to sugar production of these Islands have shown that imperceptible though the climatic changes are to us human beings, they are nevertheless reflected in the yield of sugar cane crops. The accompanying chart appears to suggest that the climate of our sugar plantations is of greater significance than we have hitherto credited it with.

Climate and Variety Distribution

It is generally recognized that climate, particularly temperature, is the most important factor in the distribution of crops. In these Islands, we talk of good H 109 districts, good Yellow Caledonia districts, etc., implying, thereby, that there are certain localities eminently suited, by virtue of their climate, to grow H 109 or Yellow Caledonia. This chart lends general support and gives a broad definition to the view thus expressed.

If we locate the plantations where H 109 grows well, we will see that they fall within certain well defined limits. Good H 109 plantations have an annual maximum temperature of over 82°, a range of temperature of over 16°, and rainfall of less than 25 inches a year, and they are all irrigated plantations. A good H 109 district is, therefore, one with high maximum temperature, fairly high range of temperature, and ample, well distributed water.

All the typical Yellow Caledonia plantations are, on the other hand, located below 80° maximum temperature, have a range of 14-16°, an annual rainfall of over 75 inches and are all unirrigated.

In the area between these two climatic districts, one of H 109 and the other of Yellow Caledonia, we encounter plantations some of which lean towards H 109 and others towards Yellow Caledonia. These plantations between 80° and 82° are perhaps in an undefined territory not knowing where they belong. These are often the places looking for some new variety that will just fit in.

Climate and Juice Quality

In our recent studies of weather and the quality of juice at Ewa (*Hawaiian Planters' Record*, Vol. XXXV), it has been shown that range of temperature has a great influence on the quality of juice. Within certain limits, a high range is

Explanation of Chart

This chart gives information on four points: (1) the daily mean maximum temperature, (2) the daily mean minimum temperature, (3) the mean daily range temperature (range=difference between maximum and minimum temperature), (4) the total annual rainfall. Each plantation is located on the chart by its maximum and minimum temperatures. Thus Pahala is seen to have an annual maximum temperature of 81.1° and an annual minimum of 61.4°; Ewa a maximum of 83° and minimum of 64.6°. Diagonal lines are drawn through points having the same difference between maximum and minimum temperature. These are the lines of equal range of temperature. For the sake of simplicity these lines have been placed two degrees apart, giving ranges of 12-14°, 14-16°, etc. Now, when we look at a point on the chart, say Ewa, we may see that it has an annual mean maximum temperature of 83°, an annual mean minimum temperature of 64.6°, and it has a mean daily range of temperature of 18-20°, or 18.4 to be exact.

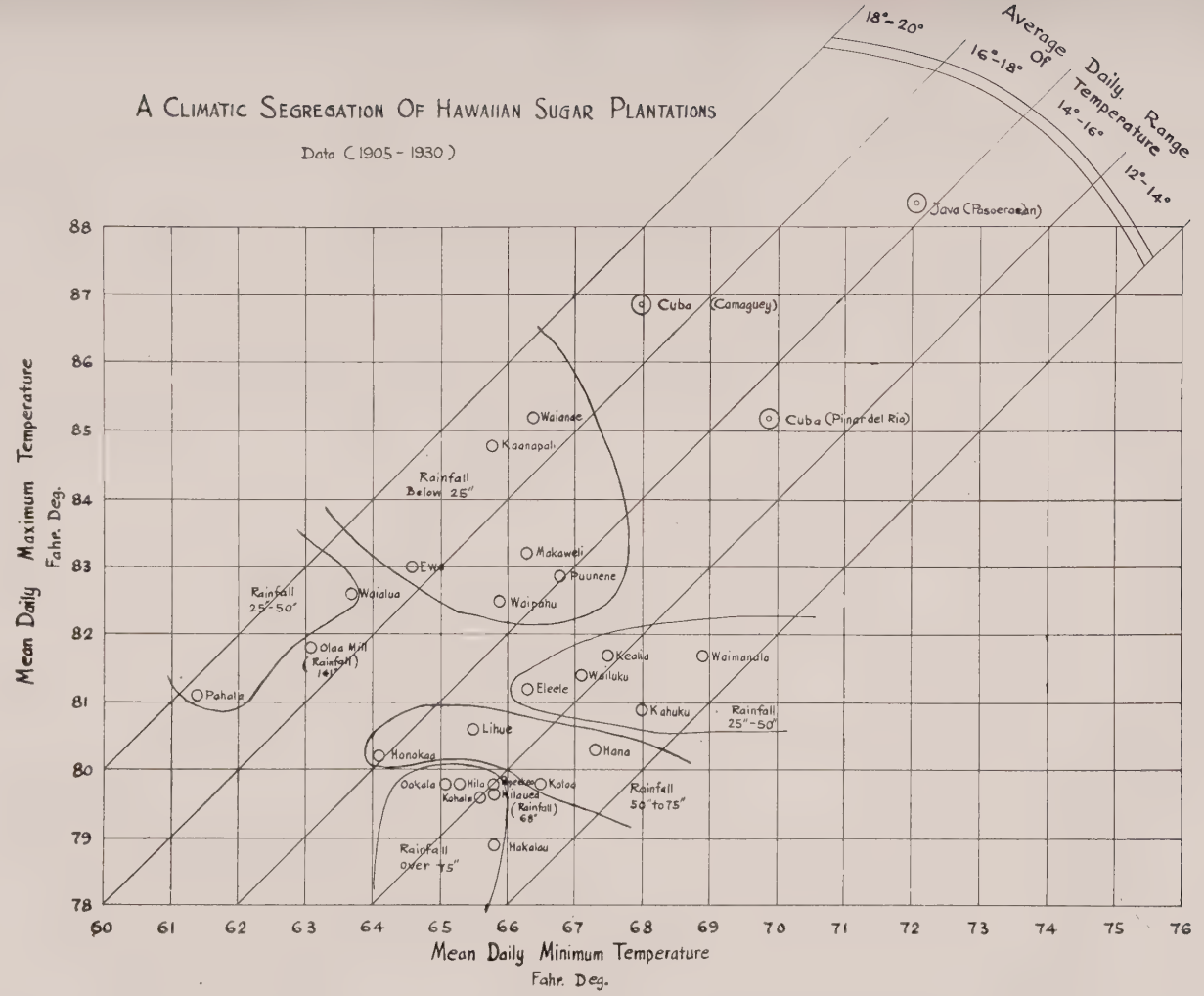
The plantations are further grouped according to total annual rainfall. Again for the sake of simplicity the divisions are from 0-25 inches, 25-50 inches, etc. A free hand curve is drawn around plantations belonging to the same rainfall group. The chart is now complete and from it we read that Ewa Mill has an annual mean maximum temperature of 83°, an annual mean minimum temperature of 64.6°, an annual daily range of temperature of 18-20°, and it has a total rainfall of less than 25 inches a year.

On this chart as we go from the bottom upwards, the maximum temperature increases; as we move from the left to the right, the minimum temperature gets higher and higher, and as we move from the right to the left diagonally across the chart, we encounter plantations having greater ranges of temperature.

Java and Cuba have been located on the same chart, for the sake of comparison. Attention is drawn to the great differences in temperature between the plantations of these Islands, and also between Java, Cuba and this Territory as a whole.

A Climatic Segregation Of Hawaiian Sugar Plantations

Data (1905 - 1930)



Note:- Plantations noted for poor juices have the lowest daily range of temperature

generally favorable and a low range detrimental. (High range of temperature is usually obtained when the days are bright and clear and the nights cool. High range of temperature, therefore, signifies ideal conditions for the elaboration and storage of sucrose.)

The chart lends general support to our previous findings.

Within the belt of lowest range, namely 12-14°, on this chart, we find plantations like Kahuku, Waimanalo, Kaeleku, Kilauea, all of which have generally poor juices. As we move diagonally towards the left, the temperature range increases and we encounter places that generally yield cane of good quality.

Windward and Leeward Plantations

As the rainfall and temperature of these Islands are mainly influenced by the prevailing trade wind, it is to be expected that our windward plantations will have more rainfall, lower temperatures and less range of temperature. Thus in the right, lower end of the chart are located most of our windward plantations. The leeward sides of our Islands thus appear to be better for cane growing, provided there is a plentiful water supply for irrigation.

Comparative Study of Plantations

Heretofore, plantations have been compared as to efficiency, cost of production, etc., sometimes without regard to the natural climatic limitations of the places. This chart will show that in any such comparison the natural advantages and disadvantages of the climate should be taken into consideration. Unless we allow for the influences of climate, it would be unfair to compare plantations widely separated on this chart.

Remarks

This chart is purely suggestive and only broad conclusions can be drawn from its study. The reason for this, is the fact that the climatic data recorded by one weather station may not be representative of the whole plantation, and secondly there are other local factors such as exposure, sunshine, etc., which are also of significance. As more data on the climatic conditions become available, a chart of this nature will become of increasing value. In the meantime, it is hoped that this chart will arouse more interest in recording and studying the various climatic factors that affect our sugar cane crops.

Field Experiment Technique*

By Ralph J. Borden

THE TYPE OF PROBLEM

The plantation management is confronted with a mass of problems that the field experiment can help him to solve. It would be quite simple to list twenty-five or thirty of such. It is quite improbable that any plantation is in a position to tackle many issues at any one time since the amount of land, effort and money that can be devoted to field testing is limited. In order, therefore, to determine those problems that can best be decided without an experiment and those which are most vital at the time, a thorough analysis of the situation by one who is competent and fitted to judge the issues involved, is highly desirable.

Every plantation has its more or less well-established varieties, fertilizer practices, and cultural methods. Changes in these will only be considered when some permanent advantage will accrue the stockholders; hence there must be a possibility of economic gain or detection of loss before the installation of a field test can be sanctioned.

If the results of a field experiment can be applied to two or three thousand acres of the plantation, we must give such a test precedence over one from which the results can be absorbed and put into practice on only two hundred acres. A possibility of increasing sugar yields by one-half ton of sugar per acre on 2300 acres might well represent an increased income of $50,000, for which an expenditure of a few hundred dollars for a field test would have ample justification. On the other hand, if the experimental results were applicable to only a relatively few acres, then our best judgment should supersede an attempt to test the issue in the field.

When deciding which issues should be tackled first, recognition should be given to the greatest limiting factor of profit from crop yields. If water is the limiting factor, then irrigation experiments are imminent; if the variety of crop cane being grown is giving unsatisfactory returns, then variety tests should get first consideration.

In deciding which plant food issues to test in the field, it is essential that data secured from a thorough soil survey, and from analyses of cane and mill products be available. From these data, one who is well grounded in the many phases of soil sampling and analysis, and the allied subject of analysis of cane and mill products, can intelligently plan tests for the special conditions existing.

No matter what the issue: fertilizer, variety, irrigation or cultural practice, it must be viewed in the light of its possible adaptability to field testing and to its practical value to the plantation. If the results are sound, the practice should be one that can be absorbed and put into effect with corresponding gains and economies to the plantation management.

* Submitted at the ninth annual meeting of the Association of Hawaiian Sugar Technologists, October, 1930, with the endorsement of the Committee on the Technique of Conducting Field Experiments.

THE PLAN (TO REDUCE ERRORS)

Progress in any endeavor is built on an analysis of past experience. Modern methods of interpreting the results of our older field experiments have shown that variations and errors of observation have sometimes caused us to draw conclusions which were not justified from the amount of data that was available. Such experiments, however, have had their value in giving us a keener realization of the limits of field testing and the necessity for more exact methods. Twenty-five years ago the application of an additional 50 pounds of nitrogen per crop gave a response to our half-starved cane that was visible to the eye, and easily measured in gains of sugar per acre. Results from more recent experiments have shown that 50-pound differences often give no significant response on our better fed crops. Therefore, it becomes necessary to use greater accuracy and more refinement in our experimental methods and to so plan our tests that its unavoidable error will be minimized and its results not misleading.

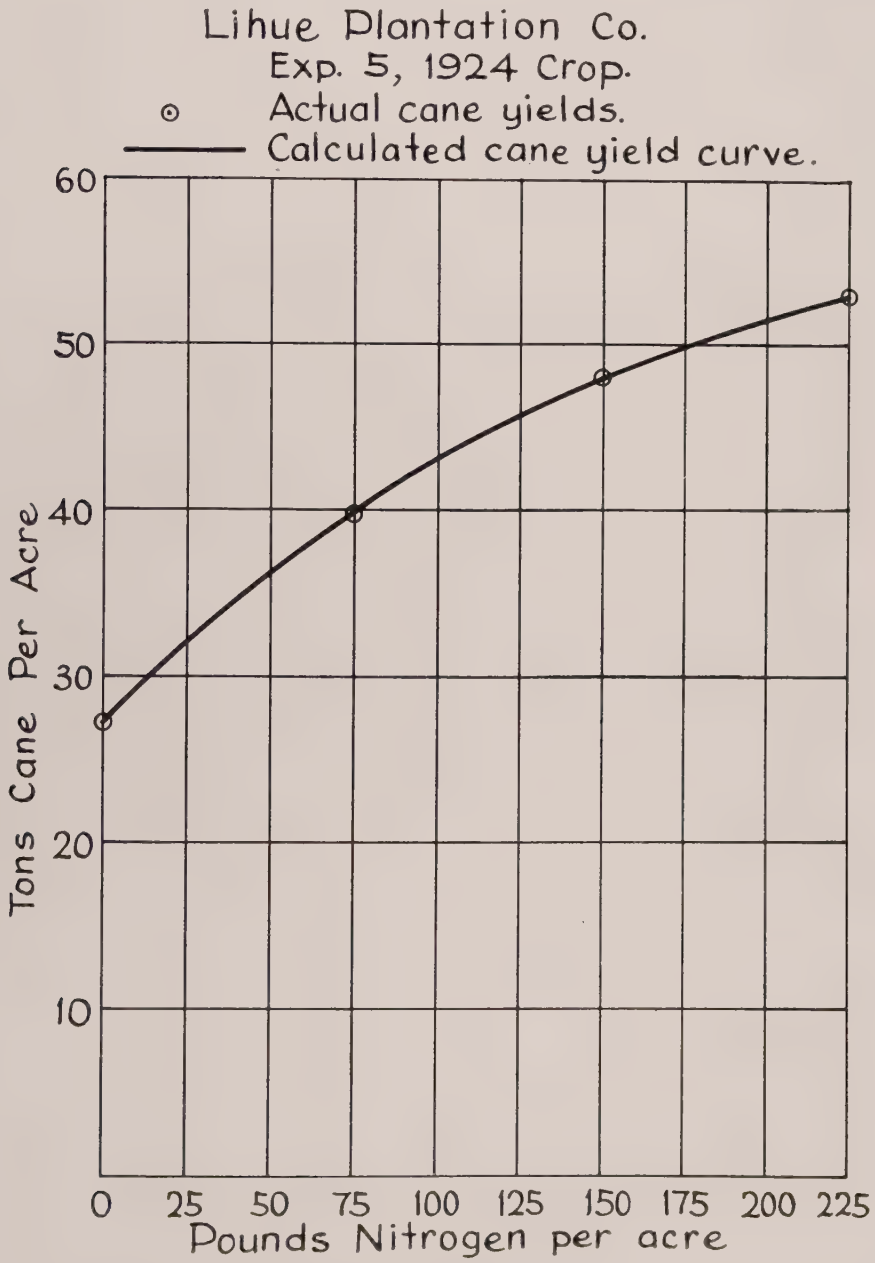
Starving cane (at left) showed clear cut response to food it was able to secure from the adjacent nitrogen-fertilized rows (at right).

The Number of Subjects:

Realization of the many independent factors which affect a living crop at every stage of its development, and knowledge of the variations which may exist in our soils make it necessary that we confine ourselves generally to only one or at the most to two closely related subjects in any individual test in a cane field. If information is desired concerning other factors, it is best to make a separate study in another test which is especially designed.

THE VARIATES OR TREATMENTS:

Simplicity should be the basis of the field experiment. The deliberately introduced variables, should be few; seldom more than four, unless every third plot is a control or check plot. With variety tests, two or three variates make it possible for our comparisons to be made on adjacent plots, and we thus get the closest to actual similarity of environments that is possible. With fertilizer tests in which



Curve constructed from results of field experiment that carried four varieties.

optimum amounts are to be sought, at least three variates are necessary (four are preferred), in order to construct a curve from the results, so that the effect of intermediate amounts can be interpolated. For such tests, until the rougher amounts have been determined, the differences between the variables should be quite large: 75 pounds for nitrogen, 100 pounds each for phosphoric acid and potash; the mid-point being the general plantation practice.

SELECTION OF THE AREA:

History:

The most important consideration in connection with the selection of an area for the field experiment is that we know something about the variations which exist within and upon our proposed experimental area, and realize how these variations may affect our results.

The location of the cane root system makes it imperative that we know something of the conditions *within* the soil mass, as well as the visible knowledge we can more easily secure from an inspection of the surface area.

On many plantations the field men can tell us much about the past history and performance of their fields. We should attempt to choose a uniform area with average fertility which is representative of the section for which the results are desired. Neither the poorest nor the most fertile spots are suitable. Areas that have carried a former field experiment or been used for seedling tests, that have had a different cropping program, been partly fallowed or pastured, received different kinds of preparation or planting, or upon which the application of fertilizers, soil amendments or plantation by-products has not been uniform should be avoided because of the residual effects that may be apparent in them for many years. Sections that are considered vulnerable points for disease or insect infesta-

tion, or which are likely to be altered during heavy rains, are best avoided, so that with tests once installed, we may have better assurance of comparable crops to harvest.

Inspection:

Evidence of the suitability of a particular area for the specific location of our field experiment is generally found by an inspection of the topography. Quickly changing contours and steep slopes are best avoided, as also are areas where there is visible evidence of uneven top soil depth, and of spot variation which may be due to any number of causes: drainage, rocks, trees, exposure.

Inspection of cane on the ground at the time of a previous harvest will often reveal areas that are not suitable for comparative plot studies.

If the test is to be installed after the stand of cane is well up, an inspection of the cane growth at two to three months will greatly assist in locating our plots where the results will be comparable.

Cane affected by Pahala blight. Familiarity with the history of the field will forestall the inclusion of such a susceptible area within the experiment.

Soil Analyses:

Soil analyses, as a guide to the placement of our field tests, are often helpful. Nullified results have been obtained from fertilizer experiments which soil analysis data would have warned against installing. Varieties may have been tested at a disadvantage on soils with an insufficient mineral food supply.

Convenience:

In selecting the area, a spot is desirable that is easily accessible to those who will contact the experiment, and that will present no barrier to the regular plantation routine, particularly at harvest time. Located where it can be frequently seen, without effort, it should do much to interest the plantation people and secure their cooperation.

Permanence:

A one-crop experiment rarely allows one to draw definite conclusions. The experiment must be continued several times before changes based on its results can be recommended. Hence, in selecting the area, we must locate with this question of time in mind, and use a spot which will be available for the proposed life of the test.

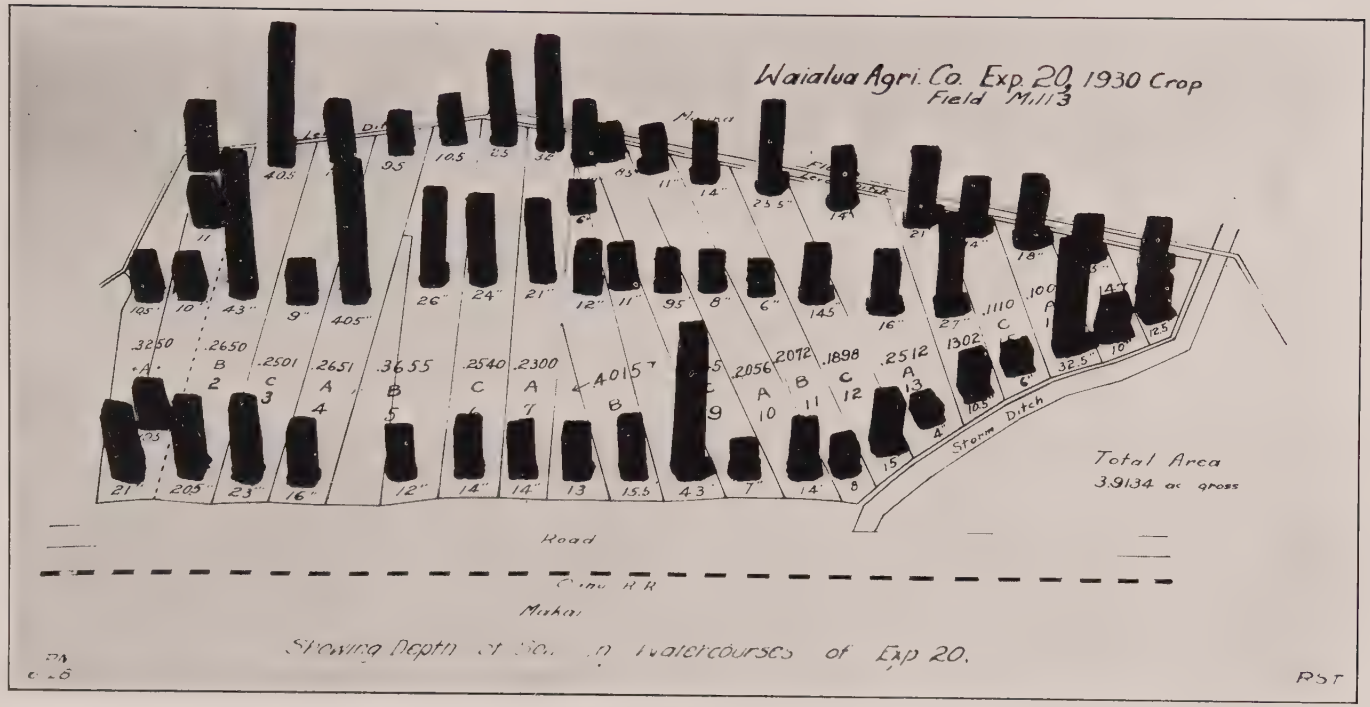
A 100 per cent germination or a full stand of cane will start all plots off on an equal footing.

Low Plot Variation:

The most important consideration in selecting the specific area for our field test is to locate it where there is the greatest probability of having only slight variations among the plots. Differences in natural soil fertility are hard to detect unless crop response to such differences is measured. Differences in soil depth and texture may be avoided through inspection of soil borings taken thruout the proposed area.

One indication of the suitability of an area for field experiments may be found in an analysis of data from tests which have been conducted in the particular field where we wish to install our layout. If former tests there show evidence of extreme variability, their general location should be avoided. On the other hand, if there is evidence of a considerable amount of similarity, the degree of such will tell us whether we can locate in close proximity to former test areas and significantly measure small differences from various treatments given.

The inherent variations in fertility that exist in specific areas can often be found from the results of a uniformly treated crop previously grown thereon. When such results are plotted, the extent and direction of the general fertility slope and the outstanding evidences of spot variation are quite apparent. The



Such differences in soil depth are apt to cause yield fluctuations greater than would be expected from surface observation.

general suitability of such area for the problem to be tested may be indicated. Especially when the test is to be first installed on ratoon cane may a plot by plot harvest of the area in the preceding crop indicate whether we have picked a suitable spot for our particular test. For those plantations that may be planning a field test program for fertilizer control the securing of yield data from several uniformly treated possible test areas in all large fields will be exceedingly valuable in determining the suitability of the area for the problem to be tested, and in devising plans to significantly measure the yield responses that may be expected in their testing program.

PLOT DESIGNS:

The design of our field experiments is largely a matter of convenience, yet there are some factors connected therewith which it is essential to have in mind if we are to increase accuracy, reduce error and get results in which we can place confidence.

Size:

The nature of the problem, the extent of suitable land available, the field practices being used, and the degree of soil variation will all have to be considered before we can decide that size of plot which will allow for the most accurate comparisons for our test.

Smaller plots have an advantage over large plots in sections where the soil variations are wide, but the smaller number of plants they carry makes them more subject to variations in stand and errors at harvest. Although large plots are not as reliable as small plots where the soil conditions are variable, the use of a Blank Test should make it possible to locate large plots with due regard to the existent inherent fertility. If there is any possibility that the necessity for accuracy will be lost sight of, or that the number of replications will be cut down, when large plots are to be used, these factors would tend to offset any advantage to be gained by using the bigger plot size.

From a study of our local conditions, the following plot sizes are recommended:

Maximum:	Doubtful if any maximum size can be set. This will depend upon the problem, the harvesting facilities and the suitability and size of the field for an adequate layout.
Minimum:	For irrigated cane, machine loaded: 2 watercourses.
Minimum:	For irrigated cane, hand loaded: 1 watercourse.
Minimum:	For irrigated cane, flume loaded: 2 watercourses in each of 2 level ditches.
Minimum:	For non-irrigated cane, wagons: 1/10 acre.
Minimum:	For non-irrigated cane, flume or rope: 1/20 acre.

Shape:

The question of shape of plots for cane experiments is very closely tied up with the matter of size. On the irrigated lands, convenience will probably determine the shape, and we will use the watercourse plot: single, doubled or multiple.

On the unirrigated area, we should be able to take advantage of the best experimental technique. There is much to be said in favor of the long, narrow plot, with its long axis laid in the direction of the greatest soil variation, for this brings the plots closest together and assists in reducing the error due to plot location. In this plan, however, it is not desirable to have less than six rows (eight would be preferable) for it will be necessary to discard the outside rows of each plot, in order to eliminate any border effect.

Replications:

The value of replication in a field experiment is in the significance it gives to the results. By repeating a treatment several times, allowance is made for most of the variations which affect results and the magnitude of errors made in conducting the test and at harvest are distributed, so that their effect upon any one particular group of plots is negligible.

No treatment, repeated in a field test, will give exactly the same result twice. The degree by which the results differ, give us our assurance of their reliability. For instance, if we measure an increase of 10 tons of cane from an extra application of potash on one plot, we have no assurance that we can get this gain again by a similar treatment. If a second plot, similarly treated gives us 9.4 tons of cane extra, we would have a little more confidence in our tonnage gain, and if 5 more plots gave us a gain of 9.6, 10.1, 9.4, 9.0 and 9.8 tons, we would be warranted in placing considerable confidence in the average gain secured. However, if the second and third plots gave us losses, and the other 4 plots showed gains of 1.1, 2.5, 6.8 and .5 tons, we would have no assurance therefrom that the extra dose of potash would actually increase our yields. Naturally therefore, *other things being equal*, the more replications we have for comparison, the greater will be the confidence that we can put in the results secured.

The number of replications to include is largely a local problem and will be determined by the following factors:

(1) The unavoidable errors of our field experiments.

(2) The degree of accuracy which can be applied to reduce the avoidable errors.

(3) The degree of difference in results which we desire to measure.

A study of the errors of Blank Tests harvested from commercial cane fields in 1929, as well as from some 450 field tests harvested throughout the Islands during the last 10 years, seems to show that we will need at least 7 replications to measure an expected difference of 10 per cent in cane yields, and that 20 replications could only measure to a 6 per cent difference. However, with the greater accuracy which can be given to field experiments, it has been pointed out by Manager E. W. Greene, of Oahu Sugar Company, Ltd., that from 6 to 10 replications can be made to significantly measure an expected difference of even 5 per cent.

On this basis, it is recommended that all field tests carry at least 10 replications, in order that we may be able to significantly measure the increasingly smaller differences which we shall have to be prepared to detect in our future field investigations.

Arrangement of Plots:

The arrangement of plots in a field test should be such as will make possible a comparison of yields from closely adjacent areas to which different treatments have been applied. Soil variation exists and will influence the results of any test, but by using an intelligent arrangement of plots we can do much to minimize its effects. Hence, the probability that the soil conditions of adjacent plots are apt to be quite similar, makes that layout which provides for comparisons of closely adjacent plots, the best we can have.

Guiding Principles: Naturally, it is realized that one cannot lay down any one "best" arrangement for experimental plots. Hence, the following principles are enumerated as a guide in the selection of a preferred layout:

(1). Keep plots which are to be compared close together; adjacent if possible.

(2). Where a "Blank Test" precedes the experiment, the location of the different units of the series of treatments may often be established from the information obtained therefrom. Plots can be so arranged that each treatment includes portions of the area which have shown a high, medium and low degree of fertility.

(3). Where the suitable area is unlimited, the checkerboard layout will give the most reliable results, and its use will make a preliminary blank test unnecessary.

(4). Where the desired area is limited, and the soil fertility slope unknown, the Latin Square arrangement will keep the plots close together and afford a means of determining the extent of the random variation.

(5). Unless the soil variation within a level ditch area is known to be a minimum, it is preferable to select an arrangement of plots so that their total area will approach a square, rather than to spread the plots out in a long narrow strip throughout one level.

(6). For direct plot-to-plot comparisons, the long sides of the plots should be adjacent.

(7). If the number of treatments is such that no practical plot arrangement can be devised to make up a sufficient number of pairs of adjacent plots for statistical study, it will be preferable to choose a layout that will allow for a determination of the soil variation which exists; i.e., Block or Latin Square.

(8). Intelligent placement of plots: (a) to take advantage of known soil fertility conditions, (b) to give all treatments equal exposure to possible soil differences, or (c) to make it possible to determine the effects of location variations. This should prove most effective in reducing the largest factor of error of our field experiments.

Practical Layouts: The different layouts as given below are arranged for tests which carry 9 or 10 replications of the number of treatments as indicated:

Irrigated Cane: (Basis: single watercourse plots)

(1). *For 2 Treatments:*

(A) *Checkerboard:* 20 plots: Ten in each of 2 levels, allowing 18 direct plot-to-plot comparisons, and giving 10 pairs of plots for statistical studies.

A X A X A X A X A X
X A X A X A X A X A

(B) *Series Arrangement:* 21 plots in one level, allowing 20 plot-to-plot comparisons, and 10 pairs for studies of significance.

X A X A X A X A X A X A X A X A X A X A X A X

(2). *For 3 Treatments:*

(A) *Checkerboard:* 36 plots: 12 plots in each of 3 levels, allowing

17 direct comparisons of A with X.
16 " " B with X.
no " " A with B.

and 9 pairs of both *A and X,* and *B and X* for statistical study.

A X B X A X B X A X B X
X A X B X A X B X A X B
B X A X B X A X B X A X

(B) *Series Arrangement:* (1) 30 plots: 10 plots in each of 3 levels, allowing

9 direct comparisons of A with X.
9 " " B with X.
9 " " A with B.

and 9 pairs of each for statistical study.

A B X A B X A B X A
B X A B X A B X A B
X A B X A B X A B X

(2) 32 plots: 16 plots in each of 2 levels. with

10 direct comparisons of A with X.
10 " " B with X.
10 " " A with B.

and 10 pairs of each for statistical study.

A B X A B X A B X A B X A B X A
B X A B X A B X A B X A B X A B

(C) *Latin Square:* 27 plots: 9 in each of 3 levels; 3 contiguous Latin Squares allowing for a determination of the effect of soil variation, and furnishing:

8 direct comparisons of A with X.
8 " " B with X.
8 " " A with B.

(Note: The 3 "Squares" may be separated if not convenient to run them together). In triplicate.

A X B X B A B A X
B A X A X B X B A
X B A B A X A X B

(3). *For 4 Treatments:*

(A) *Block:* 36 plots: 12 plots in each of 3 levels, allowing only a few plot-to-plot comparisons, but giving an arrangement by which the effects of location variation can be determined and its influence on the results allowed for:

A B C X B A X C X C A B
X C A B A B C X B A X C
B A X C X C A B A B C X

(B) *Series:* 39 plots: 13 in each of 3 levels, allowing 9 direct comparisons of A B, A X and C X—but no direct comparisons of A C and B X.

A B C X A B C X A B C X A
C X A B C X A B C X A B C
B C X A B C X A B C X A B

(C) *Latin Squares:* 32 plots: 8 plots in each of 4 levels, contiguous duplicated squares. Allowance is made for equalizing the effect of any soil variation and a few direct plot-to-plot comparisons are possible: 6 between A B, A X, B C and C X, and 2 between A C, and B X. Duplicated.

A B C X B A X C
C X A B X C B A
B C X A C B A X
X A B C A X C B

(4). *For 5 or more Treatments:*

(A) *Latin Square:* Single or duplicated; separated or contiguous, (Patterned after 3—C).

(B) *Block:* (Patterned after 3—A).

Non-Irrigated Cane: (Basis: the 1/10 acre, 8 line plot, except as noted).

(5). *For 2 Treatments:*

(A) Same as 1—B: 21 plots arranged down the slope.

(B) Same as 1—A: 2 plots wide, 10 plots long, down the slope.

(6). *For 3 Treatments:*

(A) *Checkerboard:* 36 plots: 2 plots wide and 18 plots down the slope, allowing 17 direct comparisons of A X and B X (none of A B) and 9 pairs of both A X and B X for statistical study.

X B X A X B X A X B X A X B X A X B
A X B X A X B X A X B X A X B X A X

(B) *Series:* 32 plots: 2 plots wide and 16 plots down the slope, allowing 10 direct comparisons and pairs of all varieties.

B X A B X A B X A B X A B X A B
A B X A B X A B X A B X A B X A

(C) *Latin Square:* (Basis: the 1/10 acre, 14 line plot).
(Same as 2—C)

(7). *For 4 Treatments:*

(A) *Block:* 36 plots arranged like 3—A, with 12 plots down the slope and 3 across.

(B) *Series:* 40 plots: 2 plots across and 20 down the slope, allowing 8 direct comparison and pairs of A C, 10 of A X, B X and B C, none of A B or C X.

A X B C A X B C A X B C A X B C A X B C
C B X A C B X A C B X A C B X A C B X A

(C) *Latin Square:* Duplicated (Basis: 1/10 acre, 14 line plot). (Similar to 3—C)

(8). *For 5 or more Treatments:*

(Same as 4)

Border Effect: The 8-line plot which is preferred for non-irrigated cane tests, makes it practical to remove the 2 outer rows at each side of the plot and thus eliminate the possibility of error from border effect within the experimental area.

Even with a fertilizer as easily fixed in the soil as phosphoric acid, the border effect is noticeable. (Row 8 received 200 pounds P_2O_5 per acre; rows 1 to 7 received no phosphate.)

With a 6-line plot, only one row at each side can be cut out, for it is desirable that we have at least 4 cane rows (2 rows of bundles) from which to compute comparative acre yields. At least one guard line on each side of the plot must, however, be removed.

On irrigated cane, a practical method for eliminating border effect at the ends of the cane rows at the watercourse, has not yet been found. Hence, in variety testing, it is wise to plant varieties with similar growth habits in adjacent plots.

If the plots are so arranged that each treatment has a similar amount of plot exposure to roads, trails, track lines and ditches, it will not be necessary to pro-

vide guard rows or plots of crop cane to offset the effects of favored conditions. It is a good plan to equalize the amount of fertilizer as much as possible between the test area and at least two adjacent rows of crop cane.

Control Plots: Few of our present day field tests have plots which are untreated, and in place of this untreated check plot, we have included in our series of treatments, one group which receives the standard plantation practice. Hence, our modern check plot is the one which carries the proven variety or practice with which we are comparing some unknown. (In the designs submitted, the plots designated as X are intended to represent this control plot).

CONDUCTING THE EXPERIMENT (TO AVOID ERRORS)

In the preceding discussion of "The Plan" we have considered means of minimizing the effects of the unavoidable errors of location and of distributing the errors of preparation and planting, the errors which creep in during the progress of the experiment, and some of the harvesting errors. There is still much more that we can do to cut down that error which gives us an uneven stand, and to avoid errors at harvest. It is also essential that inaccuracies of measuring areas and of determining weights be avoided, since there is no way to eliminate such effects from our plot results.

Uniformity in all of the agricultural practices, except the one which is being tested, should be the keynote for conducting the field experiment.

Area Determinations:

On unirrigated areas where the plot boundaries are well defined, the determination of the plot areas should present but little difficulty. The desired shape and size having been chosen, the plot length is usually ascertained by dividing the area by the figure obtained from multiplying the average width of row by the number of rows to be included. It is well to check the area thus laid out, by taping the boundaries and a diagonal, since an error of .01 acre can give us a large per acre yield error on the commonly used one-tenth acre plot.

On irrigated fields where irregular shaped areas predominate, extreme care is needed to secure the correct plot acreage. Undoubtedly the most accurate determination is by the use of the traverse method of surveying, yet this method may not always be the most practical in our cane field work. Some plantations have used a modification of this method: they make a traverse of the outer boundaries of the experimental area and tape the individual plots therein. The measurements are then plotted to scale and a planimeter used thereon to find the individual areas. The sum total of these individual areas should then check with the total area.

When necessary to economize time, the stadia method has generally been in use. Its accuracy, although not quite comparable with direct tape measurements on level land or when measuring the individual plot boundaries, is sufficiently great when areas are to be expressed to only two decimal places. In the hands of careful operators and with stadia rods that can be read to hundredths of a foot, it is a quick and economical method of survey and may be useful in rough, hilly lands where accurate taping is difficult.

A combined stadia—cane row measurement, offers a practical and accurate method of securing comparable plot averages. The acreage of the entire test area is determined by stadia, and row measurements of all cane therein is made. From these figures, the total linear feet of cane row per acre is obtained and from this factor and the total cane row per plot, an accurate fraction of an acre to three decimal places is calculated.

If the plots have straight sides, their area can be quite easily and accurately determined without a transit, by taping the four sides and a diagonal, thus dividing the plot into triangles and measuring all sides. Errors in this form of survey are not apt to occur providing stakes are placed at the corners to avoid using different points for measuring the sides and the diagonal. A curved boundary line can be described by means of perpendicular distances measured from its chord, and areas therein computed quite accurately. This method deserves somewhat greater consideration than it has had.

Another method of determining areas is based on the lineal feet of row in the plot. This depends for its accuracy upon the figure which is used as the average width of row, which may be difficult to obtain if hapa lines are present and unless the land is quite level and uniformly furrowed out. Areas secured by this method are perhaps accurate to within .01 acre.

On unirrigated lands the plot areas should be measured to include the area which extends half-way to the outside row of the adjacent plot and one foot beyond the end stools of the row. On the irrigated lands, measurements should be made to the center of the watercourses, and to points 2½ feet outside of the end rows at the level ditches.

Staking and Mapping:

Experimental areas should be definitely and permanently marked for the life of the experiment. Natural boundaries as base points should be accurately located. Watercourses and level ditches make excellent plot boundaries in irrigated fields. Small trails, 2 to 3 feet wide, will suffice in young cane or unirrigated fields, but will have to be supplemented with a wire fence or a good big stake in each row before the cane covers in. Plot signs or stakes are important and help to stimulate interest and secure the cooperation of the field men. Every effort must be made to set off the experimental area from the surrounding crop cane, in such a way that laborers cannot unintentionally ruin the test.

Detailed maps showing the layout, plot treatments, and location of the test area should be made as early as possible, and field overseers should have copies of these maps in order to personally interest them in the welfare of the experiment.

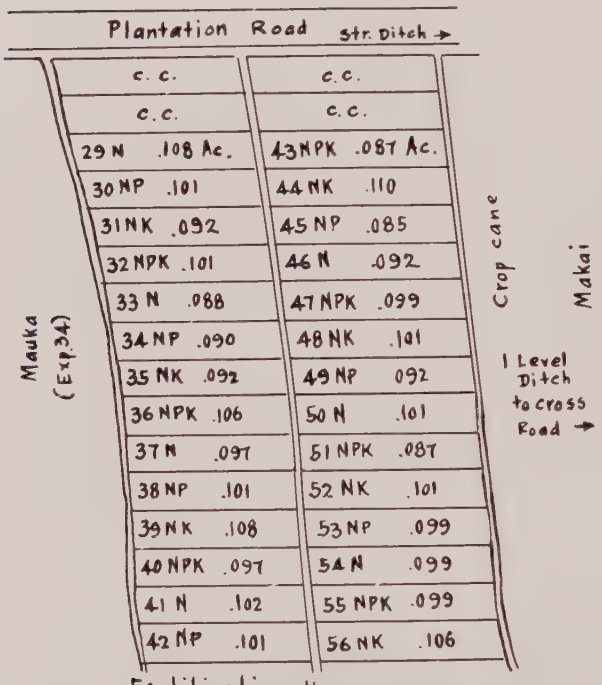
Uniformity in Operations (Except Those Under Test)

Preparation:

Plowing, subsoiling, harrowing and furrowing out must be done in such a way that all plots in the experiment will have similar conditions as regards depth and condition of seed bed, and width of rows. If the same implement and operator can do all of the machine work on the test area, and a whole gang rather than a

Pioneer Mill Co. Exp. 35, 1930 Crop

Field 30 - Honokawai. Elev. 350 ft.
Object - To determine the value of Phosphoric acid and Potash, alone and in combination.
Crop - H109, Second ratoon, previous crop harvested July 19, 1928.
Layout - 28 Irregular sized plots, each plot one watercourse.
Area: 2.742 Ac. net.



Fertilization lbs. per acre.

Plots	No. of Plots	Appl. #1 1st Season			Appl. #2 2nd. Sea.	Appl. #3 3rd. Sea	Totals		
		Am. Sul.	Ad. Phos.	Pot. Sul.	Ext. Amm	N. S.			
		30# N	300# P_2O_5	250# K_2O	50# N	120# N	N	P_2O_5	K_2O
N	7	450	—	—	250	774	260	—	—
NP	7	450	1429	—	250	774	260	300	—
NK	7	450	—	500	250	774	260	—	250
NPK	7	450	1429	500	250	774	260	300	250

O.H.L.
Aug. 1928

Am. Sul = 20 % N Ad. Phos = 21 % P_2O_5
N. S. = 13.5 % N Pot. Sul. = 50 % K_2O

The map of an experiment should show a sufficient amount of detail so as to serve as a guide for field operations, and as an aid in reestablishing the plot boundaries in case the stakes are accidentally removed.

few individuals can do all of the hand work, there will be less chance for non-uniformity in the plot operations that precede planting.

Planting:

A uniform stand of cane must be obtained before crop growth has proceeded to any great extent. Probably the factor which has the greatest effect upon the

stand is one that is closely connected with planting the seed. Good viable seed, of the same size, age, vigor, type and quality, that has been cut and handled in the same way, should be used throughout the entire area. Cuttings should be so planted that the rows receive approximately the same number of eyes per foot. Every effort must be made to avoid the necessity of replanting, but this must be resorted to until a uniform stand is secured.

Provision for replants may be a valuable practice, especially in semi-final variety tests. Single-eye seed pieces, planted in pots or in the field adjacent to the test area at the same time that the field test is planted, will provide the necessary replants to keep the plot stands comparable.

Cultivation:

In the cultural operations, where machines are used, let one operator handle all work on the test area, so that there will be little chance for the plots to receive varying treatments. If the area is under a cultivation contract, handwork throughout the plots should in general be quite uniform. When weeding is being done, care must be taken to avoid discrepancies of weed disposal, since considerable fertility is taken up by the weeds. Either they should be cut and left in the row, or they should be uniformly removed from the test plots. The same is true in regard to the removal of opala.

Fertilization:

An accurate and a uniform application of fertilizer is best obtained by carefully weighing it out for each plot, and having it applied line by line, by an experienced fertilizer gang. Skilled supervision of this work is absolutely essential to avoid errors of application and to constantly check the uniformity of application in the rows of cane.

Second season fertilization in big cane has offered a real problem. Putting it on by hand is difficult; cane is broken down and much of the fertilizer may remain on top of the trash and hence be not uniformly available to the plants. As it is usually put on in the irrigation water, the uniformity of its application is open to question because of the widely varying amounts of water that adjacent plots are apt to receive.

If a small barrel, graduated for the number of lines per plot, is used at the head of the watercourse, the application of second season nitrogen in water can be quite accurately made to the separate plots. This procedure is recommended for more general adoption if we are to have the same degree of control over second season fertilization that we give to first season applications.

Irrigation:

Recent data from Waipio indicate that there is considerable variation in the amount of water that may go on to adjacent plots during an irrigation round. This greatly complicates our attempt to give uniform treatment to our plots on irrigated lands. A check in cane growth, on a plot which may have received insufficient water to keep the moisture content of the soil above the wilting coefficient until the next irrigation, may never be noted, and yet its effect is certainly there

and in the final analysis will be checked up against the intentionally imposed treatment that the plot received. A sufficiency of irrigation water, so that the soil moisture content on all experimental plots will never reach that point at which cane growth ceases, is essential if we are to keep this complicating factor out of our results.

OBSERVATIONS (TO ASSIST IN INTERPRETING YIELD FIGURES)

Periodic observations during the growth of the crop, of the many factors which may influence it, will be exceedingly useful in interpreting the final yield figures. Statistical studies can only tell us whether or not the differences in yields are significant; the observational data if aptly recorded, will help us to understand the more probable reasons for the results obtained.

A convenient notebook form may be desirable for recording the factors which may affect the progress of an experiment. The more important factors which should be noted, at stated as well as at random intervals, are here enumerated.

(A). Comments on Weather: (Rainfall; periods of drought; abnormal temperatures; excessive winds, etc.).
1. During the first 3 months of growth.
2. During the "Boom stage".
3. During the ripening period.

(B). Damage by Repressive Agencies: (Dates of; extent of; location by plots).
1. Disease.
2. Insect pests.
3. Winds.

(C). Stand of Cane: (Specific, by plots).
1. At 30 days.
2. At 90 days.
3. Replant. (Amount, date and location).

(D). Response to Treatments:
1. General appearance and growth: At 90 days; at "closing in".
2. Following application of fertilizers.

(E). Comments on Local Conditions:
1. First rainfall after application of fertilizer.
2. Soil moisture at times of important cultural operations. Locations of poor drainage; thin soil areas.
3. Weed growth: amount, location, how long uncontrolled.
4. Tasseling: amount, location.

(F). Growth Measurements.

(G). Preharvest Juice Sampling.

Short, concise statements, made only when there is something of value to record, may be preferred to a set form for recording observations. In either case, notes concerning factors which are liable to affect a fair comparison of plot yields, should be specific and definitely identify the area to which they apply.

Regular visits of inspection to observe accidental happenings that may affect plot yields are essential in order to catch such armyworm damage as is pictured here.

HARVESTING (TO GET ACCURATE YIELD DATA)

The carelessness or the negligence of some individual, or a lack of cooperation somewhere along the line from manager to field worker during the harvesting period, is undoubtedly responsible for many of the non-understandable results of our field experiments. It is at this period that a lack of understanding or an unsympathetic attitude will nullify all of the care and attention that has gone into the test during its progress. After carefully selecting, planning and conducting the test, its value is still unknown until accurate weights or samples of all cane produced are credited to the plots which grew it.

The harvesting of an experiment will without doubt add a little extra work to someone's regular duties during a very busy season. It will probably interfere somewhat with the regular plantation routine. It may even cost the plantation somewhat more to harvest than the ordinary crop cane. But if it was worth installing, it should now be worth careful harvesting, and any sacrifice in accuracy at this time will probably mean a loss of everything that has gone into the test. Cheap experiments will seldom be worth much; accurate results cost money.

Preparations for Taking Off the Crop:

Careful plans for harvesting the experiment should be made with the harvesting luna. Details agreed to when locating the test should be adhered to. Vigilant supervision of any preliminary cuttings for fire breaks, tracks, flumes, and for plot boundary lines, will be needed to see that this cut cane is left on its original plot.

A small gang of experienced cutters, to cut out the plot boundary lines ahead of the regular cutting gangs, will prove the value of this procedure and make it next to impossible for the regular gang to mix up the cane on adjacent plots when they come along.

Cane that has been "pushed back" at the watercourses offers a means of minimizing errors at harvest.

As an aid to the harvesting of test plots, the practice of pushing back cane on level ditches and watercourse boundaries may be valuable.

CUTTING:

Cooperation with the lunas of the cutting gangs is of primary importance and will do much to assure a uniform job of cutting and topping. Placing the most intelligent cutters on the boundary lines, will be most effective in keeping the cane from each plot segregated. The use of flags at the corners of the plots helps to mark them and reduces the chance of mixing up the cane.

On unirrigated areas, the practice of cutting and bundling two rows into one, will call for special attention in making sure that the two rows belong to the same plot. With 6-line plots, and with 8-line plots when the 6 center lines are to be weighed, the cutting of the last line of one plot with the first line of the next, allows a good method of discarding one guard row on each side. If the 4 center rows only of the 8-line plot are to be weighed, then the cutter is started on the stake line and discards the 2 outer rows he cuts.

While the cane is still on the ground, an inspection to locate such factors as rat damage, dead cane, excessive sucker growth, etc., is desirable in order to provide possible explanation of wide differences in juice characteristics which may appear on sampling.

LOADING AND TRANSPORTATION:

The loaders who handle the cane on test fields must have a definite knowledge of the plot boundaries. Constant supervision of loading should be maintained.

When portable track is used, insist that the cars are not filled so full that the cane is liable to fall off before it is weighed. A little extra attention in loading and in "pinning" the cane will not be amiss. Make sure that plots are "broomed up" on to their respective cars. Credit any later "pick-up" to the individual plots where it belongs. Make it a practice to follow the loaded cars out of the field, at least as far as the main track, to note losses from cars which are most likely to occur at this time. Wagon loading demands these same precautions.

When fluming to cars, flume one plot at a time, cleaning up all the cane on it before the next one is started. Send a "marker" down the flume after the last plot bundle is dropped in, so that the cars may be changed at the chute before the cane from the next plot arrives. Watch the loaded cars as they leave the flume station to note any loss therefrom.

Careful and distinctive marking of cars and of car tickets with their respective plot numbers will greatly facilitate accurate work and lessen chances for error after the cane has left the test field. Proper precautions and cooperation with the locomotive engineer and with the mill yard boss will prevent the "breaking-up" of your string of cars at such places as will cause confusion at the mill.

WEIGHING:

The best field technique will avail us little, unless an accurate weight of all cane grown on each plot is secured.

Keep scales adjusted and checked for accuracy.

Gross Weights:

If the cane is weighed in the field, not less than every third bundle should be carefully weighed on an accurate scale. (Our studies of bundle weights show that by weighing every third bundle, we can get an accuracy of within two pounds per bundle).

If the cane is weighed on the cars, sufficient time must be allowed on the scale platform for the scale indicator to be accurately read. Precaution must be taken to see that the cane in the car on the scale is not held up by stalks which project from the ends of adjacent cars.

Net Weights:

In figuring yields per acre on cane which is weighed in the field, it is customary to weigh a very few (perhaps only one or two) bundles per plot, then to clean these of trash and non-millable canes, and reweigh. The difference or tare is then multiplied by the number of bundles in the plot, and this product when subtracted from the gross weight, gives the net cane weight upon which our comparative plot yields are to be based.

Recent studies of tare figures, indicate the probability of introducing an error of considerable size through the inadequacy of this method of determining the plot tares. Twenty bundles (one from each of 20 adjacent rows of bundles) from two "Uniformity" tests harvested during wet weather, show the following averages:

(1). No of bundles harvested from 40 cane rows, 109′ long=416.
Range of individual bundle weights: 30 to 115 lbs.
Average bundle weight: 76 lbs.
Number of bundles tared: 20.
Range of tares: 10 to 40 lbs.
Average tare per bundle: 19.7 ± 6.63 lbs.

(2). No of bundles harvested from 40 rows: 543.
Range of individual bundle weights: 55 to 110 lbs.
Average bundle weight: 84.0 lbs.
Number of bundles tared: 20.
Range of tares: 10 to 25 lbs.
Average tare per bundle: 16.5 ± 2.7 lbs.

It is quite conceivable that the nature of the cane being harvested, the experience of the cutters, the climatic conditions, and the uniformity of the burn will affect the tare. It is doubtful however whether the desired accuracy for getting an average tare can be obtained without cleaning up and reweighing a more adequate sample than a single bundle.

For cane weighed in the cars at the mill, it is necessary to get accurate weights of the "empties" in order to determine the net cane. This accuracy cannot be secured if the empty cars are hurried over the scales, or if they are occasionally ridden by laborers who are cleaning them up. The use of a standard weight for a numbered car may be subject to error, particularly when the car is wet, and is therefore not to be recommended.

SAMPLING:

A continuous running juice sample from all cane of each plot as it goes through the first mill, gives the most representative and accurate composite for analysis. The cars from each plot should be unloaded consecutively onto the carrier.

Stick and bundle samples, taken in the field, are an unsatisfactory, yet often the only practical, method of getting an indication of the quality of the cane juices. Juices from these "made-up" or "field" bundles are usually expressed by a small mill or in the last three rollers of the big mill. The greatest factor of error in this method of sampling lies in the selection of the sample in the field. Unless it is truly representative of what the plot has produced, it is quite apt to be most misleading.

Recent studies of the relative accuracies of various methods of taking samples in the field, indicate that one or two field bundles picked up at random from a tenth-acre plot, are not likely to represent the cane there. Not until we take that number of field bundles which represents 8 to 10 per cent of the total number of bundles in the plot, can we expect to have a reliable and representative sample.

When a sample is made up, by selecting 20 or 30 sticks at random throughout the plot (choosing stalks only for an equal number of top and bottom pieces), there is some indication that such a sample is more reliable than the field bundle picked at random. Sufficient data are not yet available to establish the extent of accuracy which can be secured by this method, and so it will need to be used cautiously and its results interpreted with reservations.

The recently constructed "nut cracker" sampler offers a promising means of securing a more representative juice sample from a greater number of sticks than the "made-up" bundle usually carries.

Double cane knife samples, saw cut samples, and the use of the refractometer are still questionable methods for obtaining a high degree of sampling accuracy, and cannot be recommended for general use in sampling cane stalks from field experiments. These methods were designed primarily to detect differences in seedlings.

Strictly reliable results can come only from a sample which consists of *all* the cane grown on the various plots.

RESULTS

The field experiment aims to establish representative and relative mean yields from various agricultural practices. If we apply a nitrogenous dressing to a field of cane and shortly afterwards note a distinctly greener leaf color thereon, or again at harvest note more cane on the ground, this does not constitute an experiment; it is simply an observation, and no conclusion regarding the actual value of the nitrogen dressing can be made from it. Similarly, if we divide an 80-acre field into 2 sections and plant a new variety on one-half and our standard cane on the other half, after harvesting and weighing the cane from each half, we may have a demonstration, but we certainly have not an experiment that can be relied upon to guide the plantation in its decision to adopt or reject the new cane. In the final analysis therefore, accurate and sufficient weights of cane from many

definite plots, in order to establish valid average yields, must be the end result of our field experiment.

PRESENTATION:

Figures and comments given for any experimental harvesting should be presented by the persons who have conducted the test and those originally responsible for its installation, in order that all salient points may be sufficiently stressed and valued.

Plan and History: In presenting the results of a field experiment, a careful outline of its plan and conduct is essential to an intelligent understanding of what is to follow. The time of year when the test was conducted and when fertilizer was applied are of vital importance for proper interpretation of results. Choice of data to suit the experimenter who has conducted the test should be avoided.

A brief history of the experimental area's former crops and treatment, and of similar experiments that have been conducted nearby may be useful. The salient points from soil analysis data from the experimental or closely adjacent area should be available.

Yields:

Individual plot yields must be recorded. Their conversion to plot yields per acre must be accurate, and with cane as well as with juice and sugar figures, at least two decimal points should be recorded.

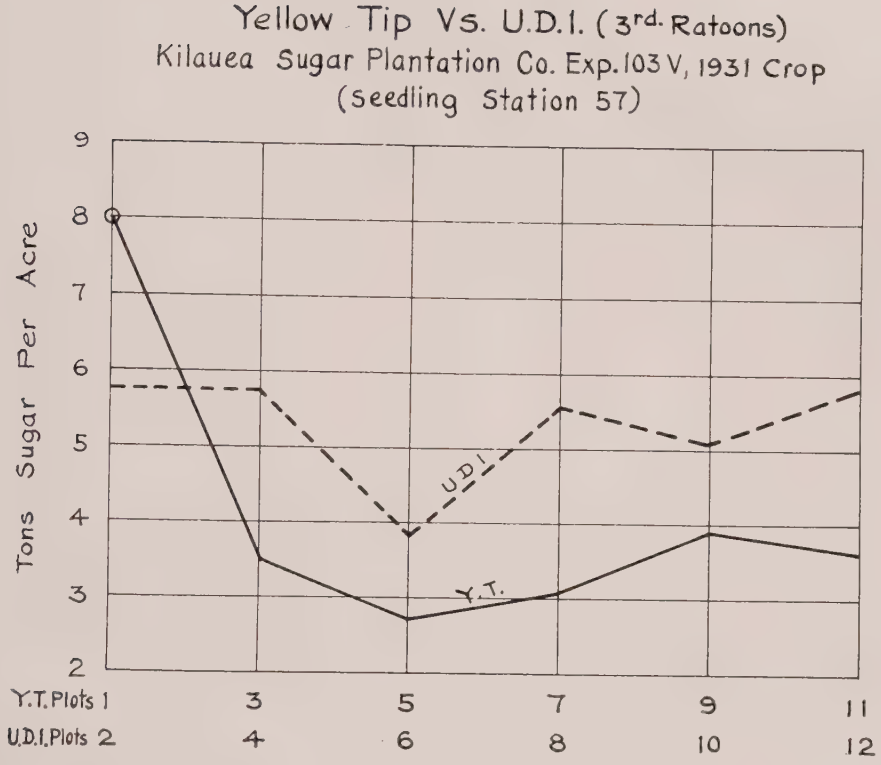
Since the modern experiment deals with treatments which are replicated a number of times, the various "Treatment" results will be further calculated and reported as averages of their individual plot yields, in tons of cane or sugar per acre.

Before summarizing the data which have been secured and are to be offered as the "Results" of our field test, careful editing of same is essential to note errors, omissions and inconsistencies. The editor who verifies the data is not justified in changing any of the originally submitted figures without distinctly marking his revisions.

After being verified, the data are generally arranged and summarized in the form of a "Table." This table should be as nearly self-explanatory as possible, and its data arranged in such a manner as to emphasize comparison and show relationships. Since long arrays of figures in tabular form often receive scant attention, a summary of the averages of varying treatments with their standard deviation should be prepared. If this summary forms the first page and is supported with the detailed results in the body of the report, the significant findings will be presented for immediate attention without loss of completeness.

For the presentation of individual plot results, the tabular form is perhaps the most difficult of comprehension. When distinctly marked on a map of the area, which shows the relative position of plots with respect to roads, ditches, gulches, trees, etc., individual plot yields (as T.-C. A.) can be quite conveniently offered for detailed plot-to-plot studies, but there is a better way to present such data for general plantation use, i.e., by means of graphs which picture the facts presented.

A properly prepared graph enables one to observe variations and correlations within a series of data. Such things as the consistent superiority of one treatment



over another and the reliability or unreliability of individual plot results, are very nicely presented by use of line graphs, and make a more lasting and vivid impression than a column of figures.

Other types of graphs are also useful in portraying facts obtained from field tests.

Observations:

No set of experimental results should be considered as complete without vital observational data to accompany it. Suggestions for recording these data have already been made.

INTERPRETATIONS:

In analyzing results of our cane field experimental work, we are looking for reliable indications of trends that will be helpful in determining plantation policies. In past years, it has been quite simple to measure the large differences that were obtained from various treatments. With the heavier yields from improved cultural practices, our present day experiments must be so designed that smaller differences can be clearly measured. When similar treatments are repeated several times, the yields are almost sure to be different and hence quite apt to be misleading. Not always do we get differences in yields which are clearly apparent and distinct enough to show definite trends from treatments given. When we do, our interpretation is comparatively simple, e.g., a regular plantation practice in

Field 66 called for a total of 200 pounds of nitrogen. Four "Amounts of Nitrogen" treatments were replicated four times on a typical and representative area in order to determine whether it would be the part of good judgment to increase the amount of nitrogen on this field which was producing well over 70 tons of cane per acre. The test yields as secured were as follows (T. C. A.):

	First Series	Second Series	Third Series	Fourth Series	Average
From 150 lbs. N	80.6	73.3	80.6	82.6	79.3
From 200 lbs. N	84.2	79.2	83.7	86.6	83.4
From 250 lbs. N	89.4	93.5	89.1	94.8	91.7
From 300 lbs. N	95.8	94.0	90.3	99.5	94.9

The trend is there and it is quite definite. Providing that sugar increase has kept pace with cane increase, the management would not go astray in increasing their nitrogen application for this field up to at least 250 pounds per acre. In fact it would appear quite evident that they could not afford to do otherwise.

Definite and distinct correlations between treatment given and yields secured are not always apparent from an inspection of the average yields. Whenever an average value is recorded, some measure of accuracy is needed, if such a quantitative value is to have a definite meaning. When none is given, we unconsciously substitute our guess as to how accurate the given figure may be. For instance, if the average yield per acre from a series of seven plots is given to us as being 64.6 tons of cane, we are likely to assume that the yield is somewhere around 65 tons, perhaps not much less than 60 or more than 70 tons. If another seven plots in the test give us an average yield of 56.4 tons, other things being equal, we are apt to consider the average of the first set as about 8 tons better than the average of the second. Without a measure of the reliability of these averages however, we are not justified in accepting them as they stand and recommending plantation practices on the basis thereof.

Fortunately, we have at our disposal a statistical method of measuring the degree of reliability that can be placed on our experimental results. This is proving exceedingly helpful in measuring the dependance that we can place upon average yield figures, and if intelligently used by an agriculturist who has an appreciation of its limitations, it can furnish a safe guide and is a useful tool.

Significance of Yield Differences:

Reliability of Average Yields: No one treatment applied to a series of plots in a field test can be expected to give exactly the same yield on more than one plot. A series of plots on our test area is a sample. Our best judgment and experience have been called upon to make sure that it is a representative sample. By itself, one single plot cannot be considered an adequate sample, nor would the average yield of 2 plots be considered a reliable measure of a yield which might be secured from the whole field. If 10 plots were used, their average would be considered more reliable than the average from 2 plots; if 20 plots were used, their average would give us still greater confidence. Hence, it becomes relatively clear that as we increase the number of units in our sample from which the most probable average yield for the field will be calculated, the reliability we can attach to

this figure will be considerably enhanced, providing of course that its representativeness is not thereby changed.

Any series of yields from a group of plots which have been similarly treated will be grouped above and below a mean or average yield. If the individual yields are scattered widely from their average, we have evidence that the sample from which the average was computed was not an adequate one, and we cannot place much confidence in such average. On the other hand, if the individual yields are grouped rather closely around their average, we have much greater assurance that such an average is a reliable one. For instance, assume yields from individual plots as follows:

Example I. 4 plots: 83, 84, 85 and 88 tons.—Average 85 tons.
Example II. 4 plots: 80, 82, 84 and 94 tons.—Average 85 tons.

In both cases the average yield is 85 tons. In the first example, however, none of the individual plot yields are scattered far from this average, and obviously we can expect that the average from another similar group of 4 plots would fluctuate fairly close to 85 tons. In the second example, the wider range of individual variation from the average yield would indicate less reliability, and greater uncertainty that 85 tons could again be secured from 4 plots of a similar group.

Statistical measurements for field experiments: It is not the purpose here to go very deeply into the subject of statistical measurements for field experiments. One cannot go very far in his interpretation of our yield data, however, without recognizing the value of such measurements and using them much as one uses a tape or a scale to check up on measures of length and weight. As measures of accuracy therefore, we should be familiar with a few of the terms and their meaning, and the general use of some of the more usable tools that statistical methods have furnished us.

Error: The word "error" as used in statistical studies does not mean a mistake such as might arise from carelessness or incompetence. Rather it is a deviation between an observed value (such as a plot yield) and the most probable value (average). Such a deviation may be caused by factors which can be controlled or it may be due to accidental or uncontrollable conditions. If it is a constant error which persists, such as might be the case if a certain plot were specially favored by the position in the field, it will affect the representative character of the series. If it is an accidental or compensating error, it will take a position in a well defined statistical distribution about its most probable value, from which we can measure its effect upon results.

Standard Deviation: This term may be used to describe with a single value, the extent by which yields of a series of individual plots deviate from their average. It may be expressed in the original unit of measurement (*tons* of cane, *degrees* Brix, etc.), or as per cent of the average. It stands as a measure of the variability within the series of plots and its magnitude indicates the degree of such variability. It offers a basis for judging the typical character of the average yield or an idea of the nature of the individual yields from which the average was computed. When we know that the standard deviation of a group of "X" plots is 9 per cent (meaning an amount equal to 9 per cent of the mean or average yield)

we can immediately form a picture in which one-third of the plot yields are within a point 9 per cent above the average, and another third are scattered to a point 9 per cent below the average. In other words, if with this 9 per cent standard deviation the average yield was 85 tons of cane, we would expect about two-thirds (68 per cent) of the individual plot yields to be between 92.7 (85 plus [9 per cent of 85]) and 77.3 (85 minus [9 per cent of 85]) tons. If on the other hand, the standard deviation was only 4 per cent, the plot yields would be closer to their average: in this case, the majority would be between 88.4 (85 plus [4 per cent of 85]) and 81.6 (85 minus [4 per cent of 85]) tons. The variation in the second case being considerably less than in the first, we have our first indication of the reliability we can place in the average yield of the series.

If we are comparing the average yields from a set of "A" plots with the average from a series of "B" plots, the standard deviation for each set will indicate whether conclusions from such a comparison can be reliable. If one average has a large standard deviation and the other a small one, the averages cannot be considered as comparable. If both of the averages are accompanied by a large standard deviation, they may be comparable but we have an indication that the comparison would be untrustworthy, if both have a relatively small standard deviation we can proceed quite confidently to use the average figures for comparison.

The standard deviation may also be used to measure the reliability of averages, in which case it would indicate that if we had a series of such averages they would be distributed about their mean with the stated standard deviation. For instance, in a recent bundle weight study, 10 samples (each sample consisting of 10 bundles of cane) have an average bundle weight of 78.8 pounds, and a standard deviation of 2.3 pounds. We would expect from this to find two-thirds of the average weights to be between 81.1 and 76.5 pounds. Actually we do find 7 of the 10 averages to be within these limits and 3 to be slightly outside of them.

Probable Error: The amount of uncertainty of any plot yield may also be expressed in terms of the probable error of a single plot (PEs). This is .6745 times the standard deviation, and represents the range of variation, both above and below the average yield, within which *one-half* of the plot yields can be expected to occur.

Attention has been called to the fact that average yields alone are inadequate and must be accompanied by some index of their reliability. The probable error finds its use at this index. It describes the distribution of errors which are due to chance, and indicates the fluctuations from the average yield, which can be expected if yields from another similar series of plots were used to calculate this average. A small probable error does not, however, prove that the statistical values are trustworthy, for the chance variation with which it is concerned is affected by the adequacy of the sampling rather than its representativeness. A constant error might be included which the probable error can tell us nothing about. It is essential to keep these things in mind if the probable error is to be intelligently used.

In reporting average yields with their probable error we indicate the amount of variation which may be expected as due to chance under the same conditions and with the same number of plots. Thus an average yield of 75.8 plus or minus

3.8 tons of cane coming from 10 plots would tell us that the chances are even (1 to 1) that the average yield of another series of 10 plots grown under the same conditions would be between 72.0 and 79.6 tons.

Odds or Chances of Occurrence: The probable error of an average yield indicates even chances (odds of 1 to 1). The standard deviation indicates that there are 2 chances, that another plot yield would fall within its plus and minus range, against one chance that it would fall outside of this range (odds of 2 to 1).

For agricultural investigations, even chances are not considered adequate, and the generally accepted practice is to ask for a greater surety than odds of 1 to 1 or 2 to 1 afford us. When we have a difference in average yields which amounts to twice the standard deviation, or one which is 3 times the probable error, we have odds of over 20 to 1 and thus a fairly high degree of probability that such an amount is not due to chance. An amount that is 3 times the standard deviation or 4 times the probable error indicates a practical certainty that it cannot be attributed to errors of sampling and hence it is presumably due to some imposed treatment.

Application of Statistical Methods to Field Experiment Results:

The following illustrations show how the more generally used statistical methods can be used with the results of field experiments.

(A). The standard deviation as a measure of the degree of accuracy of an average yield:

"A" Plots	T. C. P. A.	d	d^2	
1	62	+ 5	25	
4	51	— 6	36	
7	68	+11	121	
10	53	— 4	16	
13	54	— 3	9	Average:
16	54	— 3	9	342
6	342	—16	216	$\frac{342}{6} = 57$
		+16		

The average yield of the 6 "A" plots is 57 tons. The departures of the individual yields from this average are indicated in column "d": (the positive [plus] departures are always equal to the negative [minus] departures). The squares of the individual departures, column d^2, when summed, give the total *variance,* which in this case is 216. The total variance divided by the number of plot yields it represents gives the mean variance: $\frac{216}{6} = 36$. The standard deviation is the square root of this mean variance: $\sqrt{36} = 6$.

Mathematically this is the correct standard deviation for the example as cited. Student and other authorities, however, have recommended an additional factor of safety for crop tests when there are less than 25 replications. This factor is

introduced by using as a divisor of the total variance, one less than the number of plots:

$\frac{216}{6-1}$ or $\frac{216}{5} = 43.2$. The standard deviation thereby becomes $\sqrt{43.2}$ or 6.5.

The application of this standard deviation of 6.5 tons to the average of 57 tons of the "A" plots, tells us that if another set of 6 plots were grown under identical conditions we might expect to find two-thirds (4 plots) of them with yields between 62.5 and 51.5 tons and the other third (2 plots) outside of this range. This indicates that a conception of 57 tons as the yield which might be secured from the field as a whole, is quite liable to be wide of the actual figure which would be obtained.

With twice the standard deviation, 13 tons, we would expect to find 95 per cent of the plot yields of a similar test to fall between 70 and 44 tons, and there is an almost certainty that a range of three times the standard deviation, 19.5 tons above and below the average, hence 76.5 to 37.5 tons, would include all (99 per cent plus) of the plot yields of a duplicated test.

(B). The standard deviation as a measure of the significance of the difference between two average yields:

Eight "A" plots averaged 89.8 tons of cane and had a S. D. of 4.7 tons.

Eight "B" plots averaged 84.5 tons of cane and has a S. D. of 7.5 tons.

Is the difference between 89.8 and 84.5, which is 5.3 tons, a significant one?

The probability that shall be taken as significant is a matter of individual preference but the standard deviation will tell us what the probability is, and then we must decide whether we are to accept the margin of safety it indicates.

The standard deviation of a difference between two treatments is equal to the square root of the sum of the squares of the two separate standard deviations.

The S.D. of this difference (5.3 tons) is $\sqrt{(4.7)^2}$ plus $(7.5)^2$ or $\sqrt{22.09}$ plus 56.25 which is equal to 8.8 tons, and it indicates that the difference of 5.3 tons might well have been due to chance alone and hence cannot be considered as having been caused by the difference in treatment of the plots.

If these same average yields had carried smaller standard deviations, i.e., 89.8 tons plus or minus 1.1, and 84.5 tons plus or minus 1.3, we would then have had the following standard deviation of their difference:

$$\sqrt{(1.1)^2 \text{ plus } (1.3)^2} = \sqrt{1.21 \text{ plus } 1.69} = \sqrt{2.90} = 1.7$$

In this case the actual difference of 5.3 tons would be practically three times its standard deviation and the chances would be 369 to 1 that such a difference was due to the treatment given the "A" plots. Hence, we have an almost certainty that it is not a chance difference and can feel quite confident that it has been secured from adequate data and is therefore reliable.

In case the actual difference had been only twice the size of the standard deviation, our odds would have been in the ratio of 21 to 1 that such a difference was not due to chance; thus a fairly high degree of probability that the difference in treatment was responsible for the average difference in yield.

In place of measures of standard deviation, the probable error measure is

frequently used. In most American publications, a plus or minus sign (±) placed before a value, indicates the probable error of the mean. For instance: 80.1 ± 2.4 tons of cane, indicates a probable error of 2.4 tons of cane attached to an average yield of 80.1 tons. In our interpretation of differences in yield we would need to remember that it will take three times the probable error to give us the same significance which is indicated by twice the standard deviation.

The following table (1) may be useful in summarizing the odds and the degrees of probability indicated by different amounts of the Standard Deviation and the Probable Error:

(1) From page 241 "Principles and Methods of Statistics" by Chaddock.

Amounts of the S. D.	Chances of Occurrence	Amounts of the P. E.	Chances of Occurrence	Degrees of Probability
±0.6745	1 to 1	± 1	1 to 1	Equal
±1.0	2 to 1	± 2	4½ to 1	Favorable
±2.0	21 to 1	± 3	22 to 1	High
±3.0	369 to 1	± 4	142 to 1	Practical certainty

(C). Student's Method to interpret the significance of the average yield difference between adjacent paired plots:

LAYOUT

Treatment	A	B	C	A	B	C	A	B
Plot No.	1	2	3	4	5	6	7	8
T. C. A.	77	82	80	81	75	71	70	68
Treatment	C	A	B	C	A	B	C	A
Plot No.	9	10	11	12	13	14	15	16
T. C. A.	86	90	77	74	86	82	78	81
Treatment	B	C	A	B	C	A	B	C
Plot No.	17	18	19	20	21	22	23	24
T. C. A.	80	71	68	78	69	94	73	80

Plot Nos.	"A" Plots	"B" Plots	Difference (A-B)	(d) Deviation from the Av. Difference	d^2
1 and 2	77	82	— 5	9.4	88.36
4 and 5	81	75	+ 6	1.6	2.56
7 and 8	70	68	+ 2	2.4	5.76
10 and 11	90	77	+13	8.6	73.96
13 and 14	86	82	+ 4	.4	.16
19 and 20	68	78	—10	14.4	207.36
22 and 23	94	73	+21	16.6	275.56
Total			+46		
Pairs=7			—15		653.73
			+31		

$$\text{Average Difference} = \frac{31}{7} = 4.4$$

The Standard Deviation of this Average Difference $= \frac{\sqrt{653.73} = \sqrt{108.95}}{7-1}$ $= 10.4$. $\frac{\text{Av. Diff.}}{\text{S. D.}}$ or $\frac{4.4}{10.4} = .42$ which is Student's Σ and from his "Table of Odds" gives chances of about 5 to 1 that the figure of 4.4 tons is not due to chance. This 5 to 1 odds although favorable, is not considered a sufficiently high degree of probability that the amount of the difference is reliable or could be secured again.

Recommendations and Use:

After the results of a field experiment have been analyzed by a plot-to-plot comparison and by the application of some statistical measure to determine their reliability, the agriculturist who has conducted the test will be in the best position to recommend further procedure.

No radical changes in plantation field policy or practices will be made on the basis of the results from a single test. Several repetitions of the test on successive crop will be necessary if the test was a localized one. If it was a test whose results were to be applicable to the plantation as a whole or in a large part, repetitions of the test on different areas as well as through successive seasons will be in order.

If the probable error of the experiment was high, it will be advisable to check up on the possible reasons for such wide variation in plot yields. If the chance variation is too great, it may be best to discontinue the test on its present site and find a better place, rather than to repeat and again secure unreliable results. At any rate, it will be well to increase the number of replications in order to secure a more adequate sample.

If the probable error is low and we are still confident that the test area is representative and that constant errors are not being included, a repetition of the same test under the same conditions is assuredly in order.

SUMMARY

Since it is becoming more and more necessary for us to be prepared to determine smaller, significant differences than we have formerly measured, we find it necessary to take stock of our experiences and the findings of other agricultural workers, in the hope of developing an improved technique of field experimentation that will be in keeping with the high calibre of work which is existent in other branches of the Hawaiian Sugar Industry.

(1). The type of problem suitable for a field experiment on a sugar plantation should first be determined from the standpoint of its possible economic value to the plantation. With this information at hand, the expenditure of a certain sum of money to enable the agriculturist to secure a reliable answer from his experiment is justified.

(2). Factors which influence the yield of cane are not easy to control and only by using the best experimental technique can we hope to secure results that are accurate and not misleading. Hence careful planning of the test in order to reduce its errors, is our first essential.

(3). Conducting the experiment so as to avoid mistakes, and to keep therein such uniformity as will make the results comparable, is of no less importance than the plan which was made to minimize the effects of the compensating errors.

(4). Unbiased and pertinent observation data, taken during the progress of the test, will be invaluable when the yield figures are being interpreted.

(5). Adequate and intelligent supervision, and the cooperation of the entire plantation organization will be required at harvest time in order to get accurate yield data.

(6). Results will be recorded in terms of yields and observations. Their interpretation can best be made by the common sense judgment and experience of the man who has conducted the test, who has secured reliable data at its source. He can find a reliable guide and check his judgment by the application of statistical measures to his final yield figures.

Notes on Interpreting Experimental Results

By Y. Kutsunai

Before the figures are subjected to statistical methods it appears to be a good precaution to examine carefully the accuracy of the data from field experiments. The areas of the plots, the cane weights per acre, and the Brix and polarization of the juices are the fundamentals which reduced and simplified through various means permit the interpretation of the results, and, obviously, the basic data must be as free as possible from disturbing elements, which are usually excessive deviations and large mistakes.

Tons cane per acre, quality ratio, and tons sugar per acre for each plot, written directly on the respective plots on the map often reveal the fertility gradient, and the effect of an extraneous factor such as a ditch or a road, and furnish a basis for qualifying some of the yields as greater or less than normal for the locality.

The plot areas, if doubtful, can be surveyed again after harvesting the experiment. Some phenomenal yields have been traced to the mistakes in the surveying of plot areas.

The cane weights, in tons per acre, should be studied carefully, and any one that shows a suspicious figure should be recalculated from the scaleman's report. Chauvenet's Criterion may be used as an aid in deciding its disposition. The best guide, however, is the experimenter's intimate knowledge of the behavior of the plot in question during the crop life.

An example of Chauvenet's Criterion applied to cane yields follows (this step is not necessary if Student's Method is applied to the differences of paired plots):

	Tons Cane per Acre	Deviation	Deviation^2
	69.4	— 8.1	65.61
	69.0	— 8.5	72.25
	67.2	—10.3	106.09
	80.1	+ 2.6	6.76
	80.1	+ 2.6	6.76
	99.2	+21.7	470.89
Total	465.0	+26.9	728.36
		—26.9	
Mean	77.5		SD$=\sqrt{\frac{728.36}{6}}=\pm 11.02$

In the table of Chauvenet's Criterion, Table I, column 2, in the line of n=6 is 1.897, the allowable limit is $\pm 11.02 \times 1.897 = \pm 20.9$. The last cane weight, 99.2, shows a deviation of 21.7, which is greater than the limit $\pm$ 20.9. The figure 99.2 should not be used in striking the average, if the experimenter's intimate knowledge of the plot likewise indicates that the figure is doubtful. Should it so happen that the fluctuations of the plot yields appear excessive but Chauvenet's Criterion fails to single out any one plot yield to be discarded, then the natural inference is that the plots are fluctuating widely due to extreme soil variation and the arithmetic mean of such plots is likely to be inaccurate.

An example of adjacent plot comparison as in Student's Method, tested with Chauvenet's Criterion follows:

Plots C Tons Cane per Acre	Plots B Tons Cane per Acre	Gain of C over B	Deviation	Deviation ^{2}
67.8	63.6	+ 4.2	+ 1.24	1.5376
72.5	67.1	+ 5.4	+ 2.44	5.9536
68.9	63.5	+ 5.4	+ 2.44	5.9536
72.0	65.3	+ 6.7	+ 3.74	13.9876
63.6	65.7	— 2.1	— 5.06	25.6036
74.0	66.6	+ 7.4	+ 4.44	19.7136
60.8	67.1	— 6.3	— 9.26	85.7476
Total		+20.7	+14.30 —14.32	158.4972
Mean		2.96		

Standard Deviation $= \sqrt{\frac{158.4972^*}{7}} = \pm 4.76$. Chauvenet's Criterion from Column 2 and in the line of n=7 is 1.947. The allowable limit is $\pm 4.76 \times 1.947 = \pm 9.27$. The largest deviation is —9.26, which is very close to the limit 9.27. The experimenter's opinion based on the behavior of the plots can decide the disposition of —6.3 in the third column under the heading, gain of C over B.

The juices of a variety vary considerably from plot to plot. Usually this variation affects the sugar yields less than does the fluctuation in the cane weights, and in many cases the heavier cane yields are accompanied by the poorer juices so that the final results of the sugar yields are more or less compensated. In the extreme cases the poor juices and the heavy cane tonnage yield less sugar than the good juices and the light cane crop. The table below shows the compensating effect of the juices:

Plot No.	Tons Cane per Acre	Per Cent Recoverable Sugar	Deviation in Cane	Deviation in Per Cent Rec. Sugar
3	70.32	12.56	—15.62	+0.28
7	88.72	12.11	+ 2.78	—0.17
11	87.62	11.70	+ 1.68	—0.58
16	93.82	12.20	+ 7.88	—0.08
27	96.45	11.71	+10.51	—0.57
35	78.72	13.59	— 7.22	+1.11
Total	515.65	73.67	45.69	2.79
Average	85.94	12.28	7.62	.47
Per cent average deviation			8.86	3.79

The plots 3 and 35 show cane yields less than the average, but the juices are better than the average. The per cent average deviation in juice is less than that of cane weights.

* In an extremely accurate computation, the correction to be subtracted from the sum of the squared deviations is $(14.30—14.32)^2 \div 7 = +.00006$. The corrected sum of Deviation ^{2} is 158.4972—.00006=158.49714 and the S. D.$= \sqrt{\frac{158.49713}{7}}$

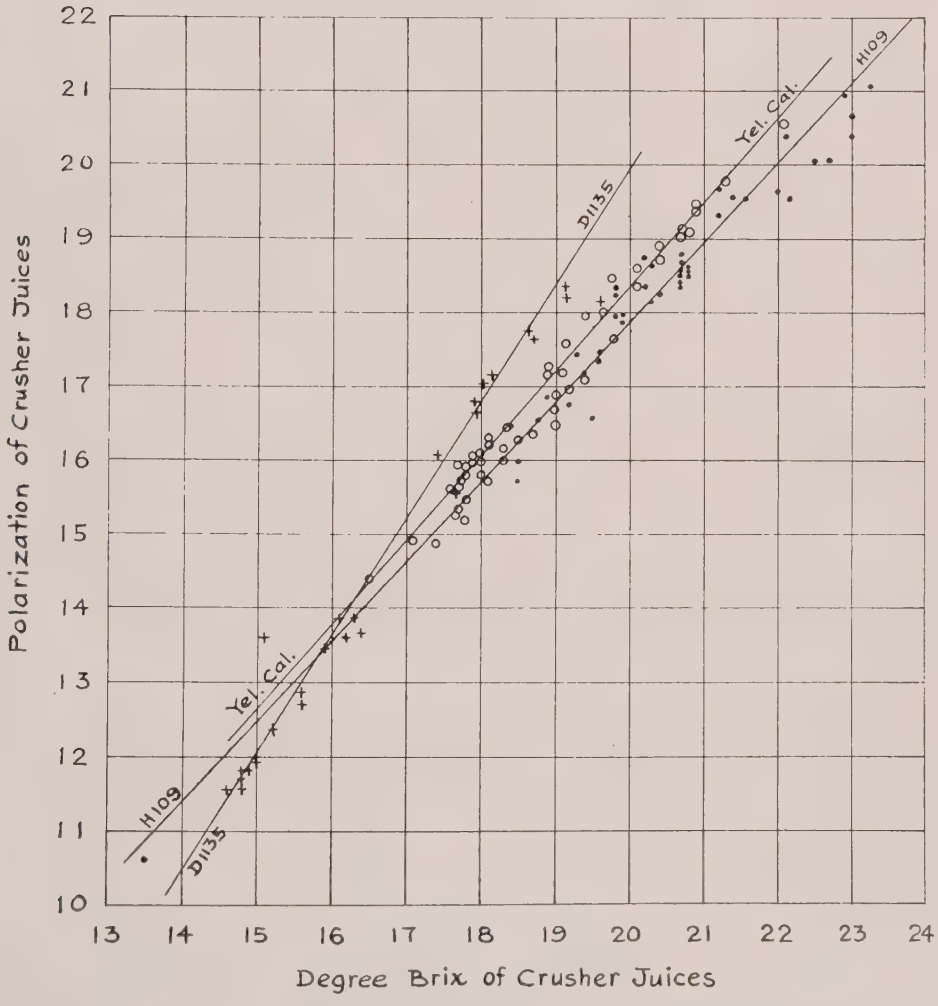
Correlation Of Degree Brix And Polarization Of The Crusher Juices Of H109, D1135 And Yellow Caledonia From Different Plantations.

• = H109 Juices from Waianae Co., Kekaha Sugar Co., Waipio Substation. Koloa Sugar Co., & Pioneer Mill Co.

+ = D1135 Juices from Honomu Sugar Co., Paauhau S.Pl. Co., & Grove Farm

o = Yellow Caledonia Juices from Hutchinson S.Pl. Co., Olaa S.Co. Hilo S. Co., Hakalau Pl. Co. & Honomu S. Co.

The H109 the D1135 and the Yellow Caledonia lines were drawn free hand through the points of respective juices.



Graph I.

The degree Brix and the polarization, on which the figure of per cent recoverable sugar largely depend, show a fortunate relation, i.e., when the degree Brix and the polarization of the juices of a variety are plotted on cross-section paper, the points fall into a line or a narrow belt which seems to be nearly straight. This characteristic of the sugar cane juices appears to be true for all varieties. With only a few exceptions the juices of a variety from many different localities when plotted together form a single line. Moreover the juices of the majority, if not all, of the varieties trace lines near to each other (see Graph I). However, when the juices in the stalks begin fermenting through deterioration prior to harvesting or delay in milling the harvested cane, the polarization goes down faster than the degree Brix, throwing the points out of alignment.

This correlation between the degree Brix and the polarization can be used in testing the correctness of the juice analyses. All the degrees Brix and the corresponding polarizations of the juices from one variety in a field test are plotted on a cross-section paper, the best fitting line is drawn free-hand among the points and the observations departing widely from the line may be discarded. In Graph II the points marked off are thought to result from erroneous observations. To save the labor of drawing an individual graph of juice characters for each variety in each test, a reference graph of juices of common varieties may be gotten up and the juices from the experiments on hand may be compared with this reference graph and the juice analyses which deviate much may be discarded.

Instead of the free-hand line, an arithmetic process may be used. The juice figures used are:

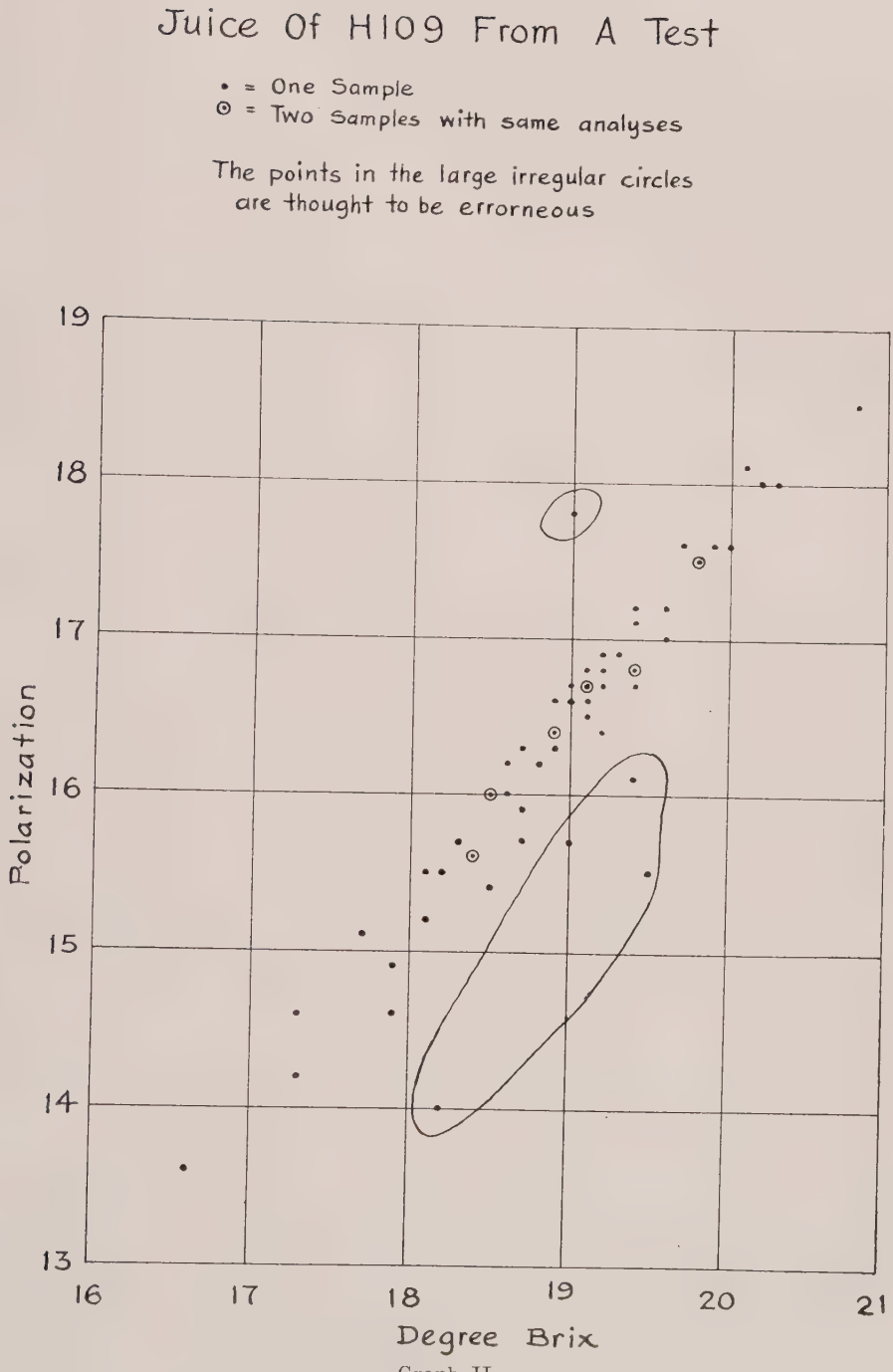
Sample No.	Degree Brix	Polarization
1	15.2	13.1
2	16.9	15.7
3	18.3	16.7
4	16.7	14.9
5	19.7	18.4

These values are formed into four totals, as in the following table for computing the values of two constants **m** and **a** in the straight line formula:

$Pol = m \times Brix + a$

Computation of **m** and **a**:

Brix	Pol	Pol x Brix	$Brix^2$
15.2	13.1	199.12	231.04
16.9	15.7	265.33	285.61
18.3	16.7	305.61	334.89
16.7	14.9	248.83	278.89
19.7	18.4	362.48	388.09
86.8	78.8	1381.37	1518.52
Σ(Brix)	Σ(Pol)	Σ(Pol x Brix)	$\Sigma(Brix^2)$


Juice Of H109 From A Test
• = One Sample
⊙ = Two Samples with same analyses
The points in the large irregular circles are thought to be errorneous
Polarization
19
18
17
16
15
14
13
16
17
18
19
20
21
Degree Brix

Graph II.

Symbolically,

$$m = \frac{\Sigma(\text{Pol} \times \text{Brix}) - \Sigma(\text{Brix}) \times \Sigma(\text{Pol}) \div n}{\Sigma(\text{Brix}^2) - \Sigma(\text{Brix}) \times \Sigma(\text{Brix}) \div n}$$

where n is the number of analyses (in this case 5),

$$a = \frac{\Sigma(\text{Pol}) - m \times \Sigma(\text{Brix})}{n}$$

Inserting the values in the place of symbols,

$$m = \frac{1381.37 - 86.8 \times 78.8 \div 5}{1518.52 - 86.8 \times 86.8 \div 5} = \frac{13.40}{11.67} = 1.148$$

$$a = \frac{78.8 - 1.148 \times 86.8}{5} = \frac{-20.85}{5} = -4.170$$

The formula of the straight line sought is:

Pol = 1.148 × Brix — 4.170

Graph III shows the five analyses and the straight line traced by the formula.

The analysis of Sample 2 may be discarded by inspection or Chauvenet's Criterion may be applied:

Sample	Brix	Actual Pol	Computed Pol	Deviation	Deviation²
1	15.2	13.1	13.2	—0.1	0.01
2	16.9	15.7	15.2	+0.5	.25
3	18.3	16.7	16.8	—0.1	.01
4	16.7	14.9	15.0	—0.1	.01
5	19.7	18.4	18.4	0	0
					0.28

$$\text{S. D.} = \sqrt{\frac{0.28}{5}} = \pm 0.237$$

Chauvenet's Criterion for n = 5 in Column 2 is 1.839. The extreme allowable deviation is ± 0.237 × 1.839 = ± 0.44, hence analysis No. 2 which shows a deviation of + 0.5 can be discarded. In Graph III, this analysis is indicated by a circle.

Each item of the basic data successfully passing the above test is accepted for further study. The erratic ones that have been discarded are kept in the table of the original data and appropriately marked to show the decision reached.

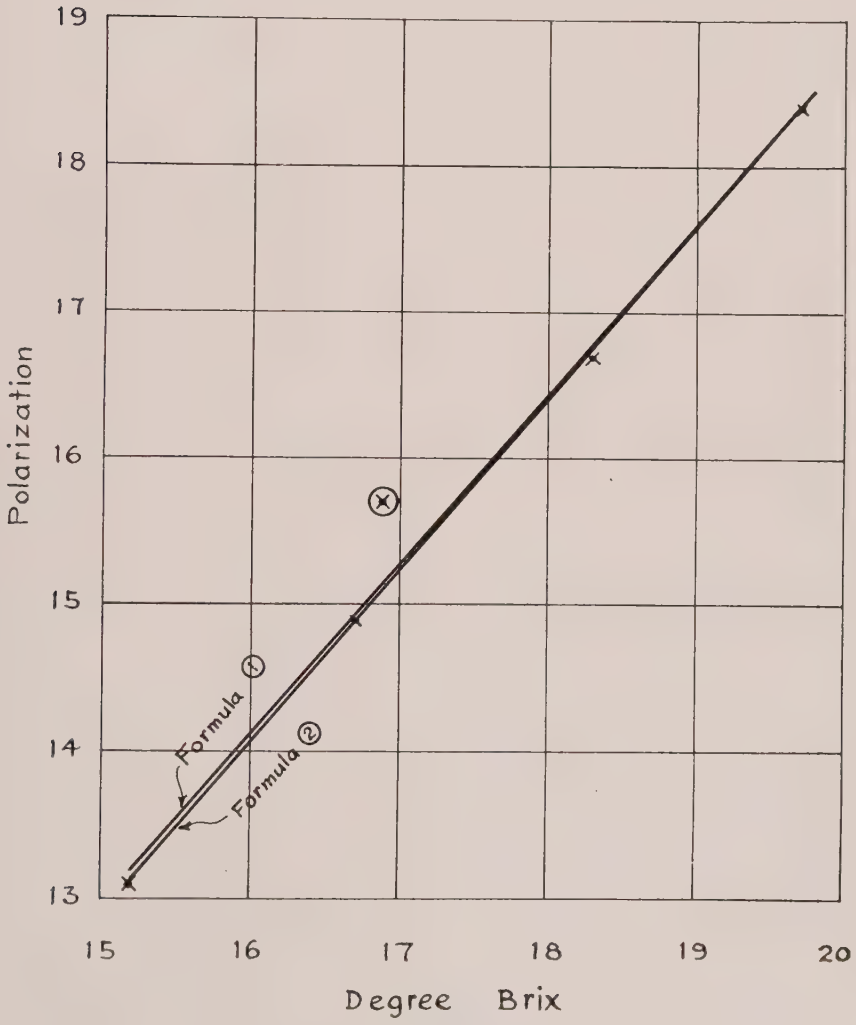
The yield of each plot is transposed into tons sugar per acre and graphed on cross section paper. Usually one plot from each of the two treatments, situated in a comparable position are plotted on the same vertical line, another pair of plots on another vertical line, and so on until all the pairs are plotted. The yields of plots of one treatment are connected with one kind of a line, for example a solid line, and those of another with a different kind of a line, such as a broken line. The general sequence of the plots in the graph is the sequence of the plots in the field itself and the direction of the "march" is not changed unless for a good reason.

"Comparable position" means not only close proximity, but also uniformity of exposure to extraneous objects such as ditches, tracts of waste land, roads, or

Analyses of D1135 Juices Modified Slightly For the Example of Applying Chauvenet's Criterion

Juice Sample	Analyses Brix	Pol.
1	15.2	13.1
2	16.9	15.7
3	18.3	16.7
4	16.7	14.9
5	19.7	18.4

The straight line is traced by
Pol. = 1.148 X Brix - 4.170 ①
After eliminating sample 2
formula changes to
Pol. = 1.172 X Brix - 4.705 ②



Graph III.

adjoining cane, and homogeneity in the soil fertility common to each of the paired plots, for instance knolls, depressions, or slopes.

If the treatment lines of the entire series of at least six pairs of plots do not cross, the experimental results can usually be accepted with confidence and the average yields of the two treatments are comparable, showing gain or loss in sugar.

If, on the other hand, the treatment lines crisscross each other often, the indication is that the treatments are without difference as far as the effect on the crop is concerned or else the plot-to-plot fluctuation is too large for the test. No further computation clarifies the situation.

Either the cane weight or the juice characteristics can be graphed if the experiment in question is thought to affect either one specifically but the most important of all is the graphing of the sugar yields in every case studied.

This method is well adapted for the study of two constants such as two varieties, off-barring against non-off-barring, chemical weed control vs. animal cultivation, etc. By applying the same process progressively, a variable involving three or more quantities say, 100, 200, 300, and 400 pounds per acre of fertilizer may be examined. First the plots of the two treatments 100 and 200 are graphed, then 200 and 300, and lastly 300 and 400. In order to obtain a large difference in the yields, 100 and 300 or 100 and 400 are often graphed whenever possible in addition to other usual combinations.

In case a decision can not be reached by the graphic method, statistical mathematics is tried. For a comparison of two treatments or two varieties in adjacent plots, Student's Method is an excellent one.

An example of two varieties in adjacent plots follows:

Tons Sugar per Acre U. D. 110	Tons Sugar per Acre Adj. Yel. Tip	Gain of U. D. 110 Over Yel. Tip	Deviation from Mean Gain	Deviation^2
5.45	5.07	+0.38	+0.02	0.0004
5.73	4.62	+1.11	+0.75	0.5625
5.21	5.05	+0.16	—0.20	0.0400
5.37	4.56	+0.81	+0.45	0.2025
4.88	5.15	—0.27	—0.63	0.3969
5.38	5.42	—0.04	—0.40	0.1600
	+ Total	+2.46	+1.22	1.3623*
	— Total	—0.31	—1.23	
	Net Total	+2.15	—0.01	
	Arithmetic Mean	+0.36		

S. D. $= \sqrt{\frac{1.3623}{6}} = 0.48$ $z = \frac{0.36}{0.48} = 0.75$. Odds from Student's Table, Table II, corresponding to $z = 0.75$ and $n = 6$ are 11.8:1, much lower than the conventional limit of significance of 30:1 odds. Whether the gain of 0.36 ton

* For extremely accurate work the sum of the squares of the deviations is corrected by subtracting (the square of the net total in the deviation column) ÷ the number of items—for example: $1.3623—(0.01^2 \div 6)=1.36318$.

sugar per acre can be considered real or not depends on the past experience of the investigator.

When a plot of a new variety is in between two plots of a check variety, the yield of the new variety is compared with the average of the two check plots and the differences thus obtained are tested with Student's Method. The components of each triplet must be not only adjacent to each other but also free from inequalities in exposure or obvious fertility value.

All experiments involving two constants such as cultivation tests, some of the plant food tests, kinds-of-fertilizer tests, cut back vs. no cut back, and others, can be handled in the same way.

Experiments with one variable, such as tests with different amounts of a fertilizer, require the determination of the best amount to apply in addition to the statistical significance of the results.

The several amounts of the fertilizer may be considered as several constants and Student's Method may be applied to the difference in yields of adjacent plots receiving different amounts of the fertilizer.

Sometimes in an experiment for the amount of fertilizer to apply, the difference in each successive increase of the fertilizer causes so small a difference in the yield that no statistical significance can be obtained. This difficulty is occasionally overcome by comparing the plots receiving a small amount of the fertilizer with those obtaining rather a large quantity. For instance if 150 pounds of nitrogen per acre shows a small gain not statistically significant, over 100 pounds of nitrogen, then 200 or 250 pounds may be compared with 100 pounds; and, when the larger increment in the fertilizer gives a distinct increase in the crop, the small gain from 150 pounds of nitrogen over 100 pounds may be considered certain. Due consideration must be exercised however in choosing the heavy fertilizer plots for the comparative purposes on account of the tendency of an excessive amount of a fertilizer to impair the juices so much more than can be made up by the increase in the cane weight, that the final sugar production may be nearly equal to or even less than that from a much smaller amount of the same fertilizer.

The average sugar yields from each amount of fertilizer are graphed, a free hand curve is passed through the points of sugar yields, and from the curve the optimum amount of the fertilizer to use can be estimated.

It is a good precaution to graph the path of average cane weights and the quality ratios. From these two lines, the free hand line of sugar yields can be checked at intermediate points.

Experiments dealing with varying degrees of a single factor such as amount or time of application of irrigation water, a single plant food element and the like may be handled by this graphic method. (Graph IV.)

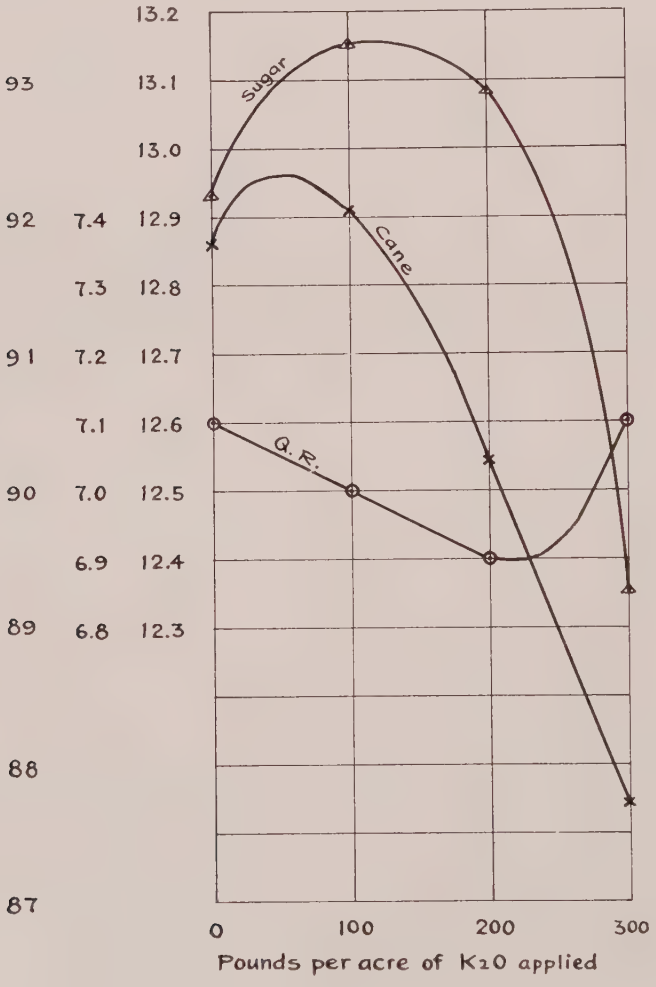
The yield curve computed by the method of Spillman is excellent for interpolating the sugar yields between any two quantities of a variable factor tested.

Experimental results from tests with two variables can be shown by a frequency surface similar to Graph V or more satisfactorily by a model similar to the one shown in photograph (A).

The Increasing Amounts Of K_2O Affecting The Per Acre Yields Of Cane and Sugar

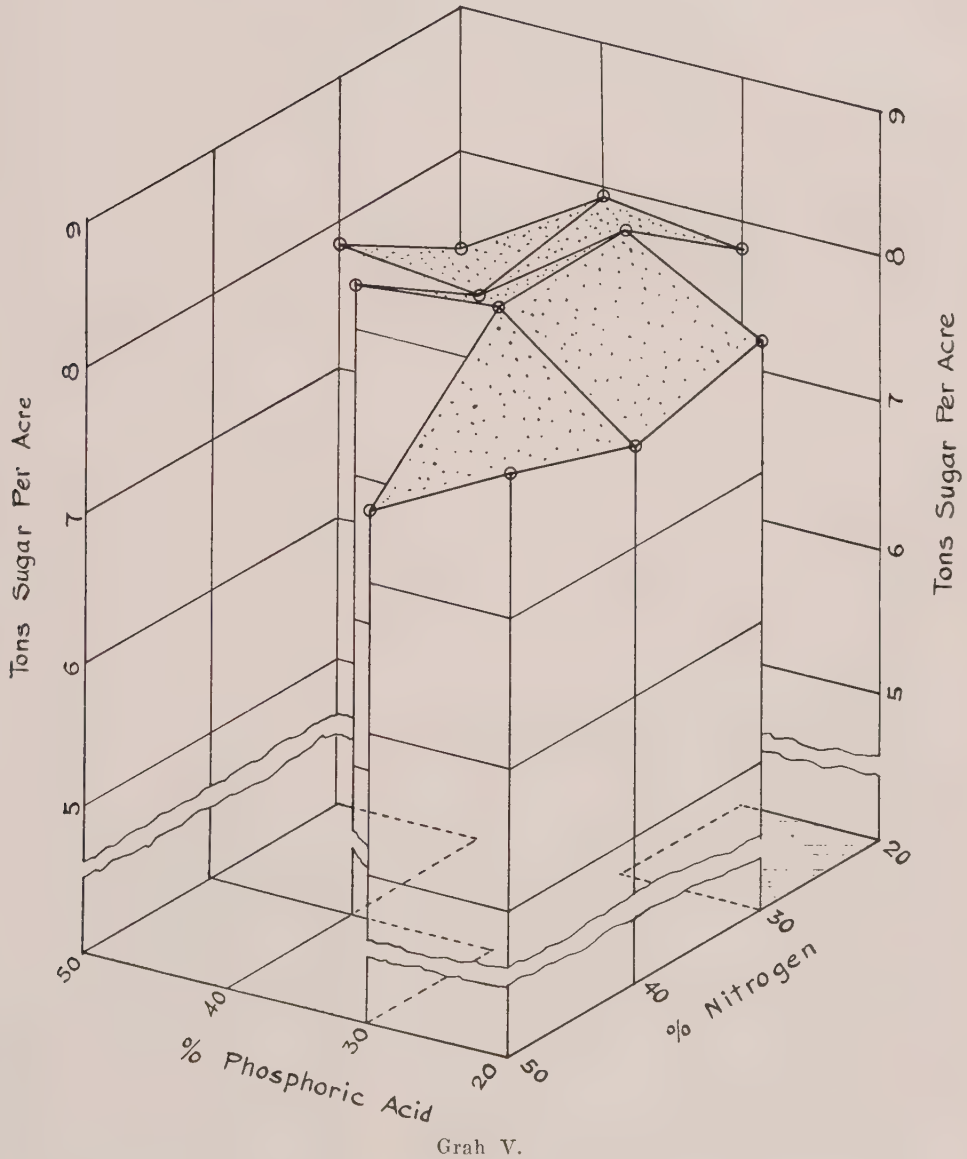
Harvesting Results Used

Plots	No. of Plots	Fertilizer Applied lbs. P.A. N.	P_2O_5	K_2O	Cane T.P.A.	Q.R.	Sugar T.P.A.
A	6	256	200	0	91.80	7.1	12.93
B	6	256	200	100	92.03	7.0	13.15
C	6	256	200	200	90.22	6.9	13.08
D	6	256	200	300	87.70	7.1	12.35



Graph IV.

Tons sugar per acre from combinations
of various percentages N, P_2O_5 and K_2O
The total of N, P_2O_5 and K_2O is 100%



Grah V.

The surface of the model represents 8 tons sugar per acre. Clearly the model shows that the heavier the fertilizer the earlier it must be applied.

Fertilizer tests laid out according to the triangular system in which the sum of the three factors equal 100 per cent may be classed under the two-variable experiments, and the rectangular model may be used if so desired, because the amounts of any two fertilizers can be taken as variable while studying the harvesting results and the third fertilizer can be left out of consideration until the decision is reached.

A model drilled to represent the layout of the triangular coordinates as shown in photograph (B) is just as simple to interpret as the rectangular model.

Graph V also represents the data of this triangular test in the form of a frequency surface.

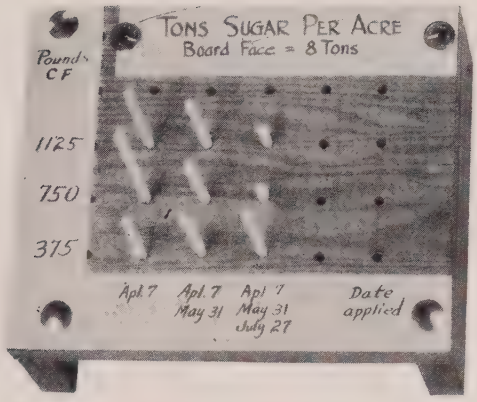
If three factors vary independent of each other, for example, nitrogen increasing 75, 150, 225 and 300 pounds per acre, phosphoric acid 100, 200, 300 and 400, and potash 0, 100, 200 and 300, the harvesting results may be gathered in a tabular form as shown below:

SUGAR YIELDS, TONS PER ACRE
(Reconstructed from the yield curves)

	0 Lbs. K_2O	100 Lbs. K_2O	200 Lbs. K_2O	300 Lbs. K_2O
	75 Lbs. N			
100 lbs. P_2O_5	7.6	7.4	7.2	
200 " "	7.5	7.3	7.1	
300 " "	7.3	7.2	7.0	
400 " "				
	150 Lbs. N			
100 " "	8.0	7.9	7.8	
200 " "	8.1	8.1	7.7	
300 " "	7.9	7.8	7.7	
400 " "	7.7	7.6	7.6	
	225 Lbs. N			
100 " "	8.1	8.3	8.2	8.0
200 " "	8.2	8.4	8.3	8.1
300 " "	8.1	8.4	8.2	8.0
400 " "	7.9	8.2	8.0	7.9
	300 Lbs. N			
100 " "		7.6	7.7	7.5
200 " "		7.8	7.9	7.7
300 " "		7.9	8.0	7.8
400 " "		7.9	8.0	7.7

An experiment as extensive as the above is more suitable for pot tests than for field tests even after eliminating the obviously poor combinations. The four sections of the table are made up into a model, and the center of high yields in each section is estimated as follows:

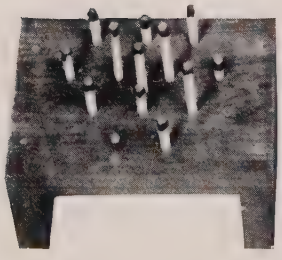
Pounds per Acre			Sugar Yield Tons per Acre
N	P_2O_5	K_2O	
75	100	0	7.6
150	200—	50—	8.1
225	200+	100+	8.4
300	300	200	8.0

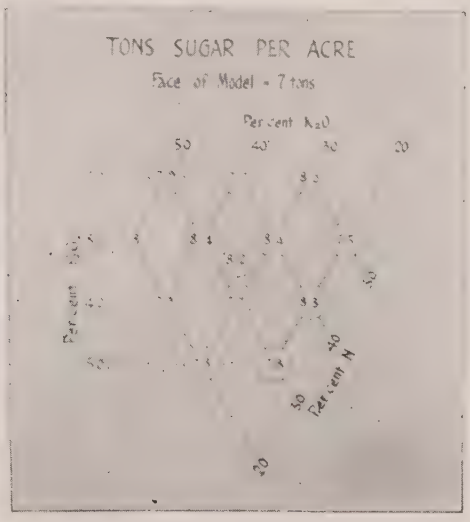


(A) The model represents the sugar yields from a test for different amounts and time of applying a mixed fertilizer (M. F.) as a spring dressing.

The harvesting results shown in the photograph are:

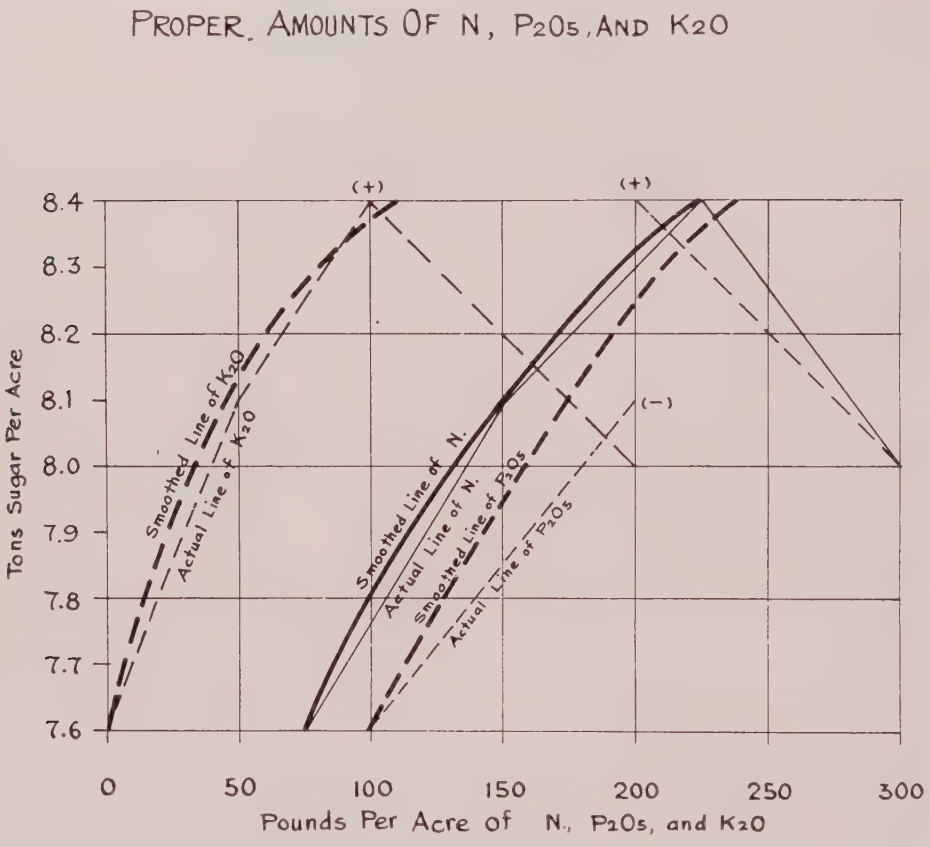
Plots	Pounds M. F.	Doses	Date Applied	Sugar Yield
A	375	1	April 7	9.07
B	"	2	April 7, May 31	9.21
C	"	3	April 7, May 31, July 27	9.11
D	750	1	April 7	9.76
E	"	2	April 7, May 31	8.99
F	"	3	April 7, May 31, July 27	8.33
G	1125	1	April 7	9.42
H	"	2	April 7, May 31	9.12
I	"	3	April 7, May 31, July 27	8.41





(B) In this photograph the composition of the best ratio appears to be 37 per cent nitrogen, 32 per cent phosphoric acid, and 31 per cent potash.

These figures when found reliable are plotted on cross section paper and free hand curves are drawn through the points of the ascending yields. The descending branches of the curves are of no interest in the practical work. From these free hand curves (Graph VI), the following table of best proportions is constructed:



Graph VI.

Pounds per Acre			Sugar Yields Tons per Acre
N	P_2O_5	K_2O	
75	100	0	7.6
87	112	6	7.7
102	130	15	7.8
117	146	25	7.9
132	161	35	8.0
150	175	45	8.1
168	191	63	8.2
198	210	83	8.3
230	237	110	8.4

An easy but lengthy mathematical method suitable for studying many variable factors is described in chapter 14, "Method of Correlation Analysis," by Mordecai Ezekiel.

Plant food tests often do not contain sufficient replication of the plots for applying statistical analysis. The conclusions drawn are indicative, but not quantitative. However, the number of comparisons from various layouts is of interest.

P_2O_5 and K_2O only are tested when N is applied to all the plots. The treatments are N, P, K and PK and the possible comparisons are:

NPK vs. NP, NK and N
NP vs. NK and N
NK vs. N

When nitrogen also is tested, the treatments are NPK, NK, PK, N, P, K and O (no fertilizer) and the comparisons increase to 22 as follows:

NPK vs. NP, NK, PK, N, P, K and O
NP vs. NK, PK, N, P, K, and O
NK vs. PK, N, P, K, and O
PK vs. N, P, K and O

A small amount of a certain fertilizer, particularly P_2O_5 and K_2O, may become fixed near the surface of the ground and remain unavailable to the cane plant. No response of the cane crop to a fertilizer may mean sometimes non-availability due to faulty application rather than a sufficient supply in the soil.

In all cases the common sense and the general knowledge of the experimenter take precedence over the statistical methods.

TABLE I
CHAUVENET'S CRITERION

Compute standard deviation by the usual formula, S.D. $= \sqrt{\frac{\Sigma D^2}{n}}$

Enter Column 1 with the value of **n** used in computing the foregoing standard deviation. In the same line and in Column 2 the correct value of the limit of deviation is found. Multiply the standard deviation by the limit of deviation. The product is the limit of allowable fluctuation.

Column 1 n	Column 2 Limit of Dev.
3	1.694
4	1.771
5	1.839
6	1.897
7	1.947
8	1.991
9	2.031
10	2.066
11	2.098
12	2.127
13	2.154
14	2.181
15	2.203
16	2.225—
17	2.245—
18	2.264
19	2.282

Column 1	Column 2
n	Limit of Dev.
20	2.300
21	2.316
22	2.332
23	2.346
24	2.361
25	2.374
26	2.387
27	2.400
28	2.412
29	2.424
30	2.435—

Table of Odds by Student's Method*

Table II

Z.	n=2	n=3	n=4	n=5	n=6	n=7	n=8	n=9	n=10	n=11	n=12	n=13	n=14	n=15	n=16	n=17	n=18	n=19	n=20	n=21
.1	1.14	1.22	1.29	1.35	1.40	1.46	1.50	1.55	1.59	1.64	1.68	1.72	1.76	1.80	1.84	1.88	1.92	1.96	2.00	2.03
.15	1.21	1.35	1.46	1.56	1.66	1.75	1.83	1.92	2.00	2.08	2.16	2.24	2.31	2.39	2.47	2.54	2.62	2.69	2.77	2.84
.2	1.29	1.49	1.66	1.82	1.97	2.12	2.26	2.41	2.55	2.70	2.84	2.99	3.14	3.29	3.44	3.60	3.75	3.91	4.08	4.24
.25	1.37	1.64	1.88	2.10	2.32	2.54	2.75	2.97	3.10	3.41	3.64	3.87	4.11	4.36	4.60	4.86	5.12	5.39	5.66	5.94
.3	1.46	1.81	2.13	2.44	2.76	3.08	3.41	3.75	4.11	4.48	4.86	5.27	5.69	6.13	6.59	7.08	7.59	8.12	8.68	9.27
.35	1.54	1.98	2.40	2.81	3.24	3.68	4.14	4.62	5.13	5.67	6.24	6.84	7.47	8.15	8.86	9.62	10.4	11.3	12.2	13.1
.4	1.64	2.18	2.72	3.27	3.85	4.48	5.15	5.88	6.67	7.53	8.45	9.47	10.6	11.8	13.1	14.5	16.0	17.7	19.5	21.5
.45	1.73	2.39	3.05	3.75	4.51	5.33	6.24	7.24	8.34	9.54	10.9	12.3	13.9	15.7	17.7	19.8	22.2	24.8	27.7	30.7
.5	1.84	2.62	3.44	4.35	5.36	6.50	7.80	9.26	10.9	12.8	14.9	17.3	20.1	23.3	26.8	30.8	35.4	40.7	46.4	53.1
.55	1.94	2.85	3.85	4.97	6.25	7.72	9.42	11.4	13.6	16.2	19.2	22.7	26.7	31.3	36.5	42.7	49.5	57.5	66.6	77.1
.6	2.05	3.12	4.33	5.75	7.42	9.42	11.8	14.6	18.0	22.0	26.8	32.4	39.3	47.3	56.8	68.4	81.6	98.0	117.	140.
.65	2.16	3.39	4.82	6.54	8.62	11.2	14.2	17.9	22.5	27.9	34.6	42.5	52.2	63.9	77.7	95.2	115.	140.	168.	203.
.7	2.27	3.69	5.41	7.55	10.2	13.6	17.8	23.1	29.8	38.1	48.5	61.5	77.7	99.0	124.	155.	195.	249.	302.	384.
.75	2.39	3.99	5.99	8.55	11.8	16.0	21.4	28.3	37.2	48.3	62.7	81.0	104.	134.	171.	216.	277.	356.	434.	555.
.8	2.51	4.33	6.70	9.82	14.0	19.5	26.8	36.5	49.3	66.1	88.3	118.	158.	207.	277.	356.	475.	624.	832.	1110.
.85	2.62	4.66	7.39	11.1	16.1	22.9	32.1	44.5	61.1	83.7	114.	155.	207.	277.	369.	499.	666.	908.	1110.	1428.
.9	2.75	5.04	8.22	12.7	18.9	27.7	40.0	57.1	81.0	114.	160.	226.	311.	434.	587.	832.	1110.	1666.	1999.	2499.
.95	2.87	5.41	9.03	14.2	21.7	32.4	47.8	69.4	100.	144.	207.	293.	416.	587.	832.	1110.	1666.	2499.	3332.	3332.
1.0	3.00	5.83	10.0	16.2	25.5	39.2	59.2	89.1	132.	195.	293.	434.	624.	908.	1428.	1999.	3332.	4999.	9999.	9999.
1.05	3.12	6.24	11.0	18.2	29.1	45.7	70.4	108.	163.	243.	369.	555.	832.	1249.	1999.	2499.	4999.	4999.		
1.1	3.26	6.69	12.1	20.6	34.0	54.9	87.5	138.	216.	332.	525.	832.	1249.	1999.	3332.	4999.	9999.	9999.		
1.15	3.39	7.13	13.2	22.9	38.7	63.5	103.	166.	262.	416.	666.	999.	1666.	2499.	3332.	4999.				
1.2	3.52	7.63	14.5	25.9	44.9	75.9	127.	212.	344.	555	908.	1428.	2499.	3332.	4999.	9999.				
1.25	3.65	8.11	15.7	28.8	50.8	87.5	151.	255.	416.	713.	1110.	1666.	3332.	4999.	4999.					
1.3	3.79	8.64	17.2	32.3	58.5	104.	184.	322.	555.	999.	1666.	2499.	4999.	9999.	9999.					
1.35	3.92	9.16	18.6	35.8	66.1	119.	216.	384.	666.	1249.	1999.	3332.	4999.							
1.4	4.07	9.74	20.3	40.0	75.9	142.	262.	475.	908.	1666.	3332.	4999.	9999.							
1.45	4.20	10.3	21.9	44.0	85.2	163.	302.	555.	1110.	1999.	3332.	4999.								
1.5	4.34	10.9	23.9	49.0	98.0	191.	369.	713.	1428.	2499.	4999.	9999.								
1.55	4.48	11.5	25.7	53.9	109.	216.	434.	832.	1666.	2499.	4999.									
1.6	4.62	12.2	27.7	60.0	124.	255.	525.	999.	1999.	3332.	9999.									
1.65	4.76	12.8	29.8	65.7	138.	285.	587.	1110.	2499.	3332.										
1.7	4.91	13.5	32.2	72.5	158.	332.	713.	1428.	3332.	4999.										
1.75	5.05	14.2	34.5	79.0	174.	369.	832.	1666.	3332.	4999.										
1.8	5.20	14.9	37.0	86.7	199.	434.	999.	1999.	4999.	9999.										
1.85	5.34	15.6	39.5	94.2	216.	499.	1110.	2499.	4999.											
1.9	5.49	16.4	42.5	103.	243.	587.	1249.	3332.	9999.											
1.95	5.63	17.1	45.1	111.	269.	624.	1428.	3332.												
2.0	5.78	17.9	48.3	122.	302.	713.	1666.	4999.												
2.05	5.92	18.7	51.4	132.	332.	768.	1999.	4999.												
2.1	6.07	19.6	54.9	144.	369.	908.	2499.	4999.												
2.15	6.21	20.4	58.2	155.	399.	999.	2499.	4999.												
2.2	6.36	21.3	61.9	168.	454.	1249.	3332.	9999.												
2.25	6.51	22.1	65.2	181.	499.	1249.	3332.													
2.3	6.66	23.1	69.4	199.	555.	1428.	4999.													
2.35	6.81	24.0	73.1	212.	587.	1666.	4999.													
2.4	6.96	25.0	77.7	232.	666.	1999.	4999.													
2.45	7.10	25.9	81.6	249.	713.	1999.	4999.													
2.5	7.26	26.9	86.7	269.	768.	2499.	4999.													
2.55	7.40	27.9	91.6	285.	832.	2499.	4999.													
2.6	7.55	29.0	97.0	302.	908.	2499.	9999.													
2.65	7.70	30.1	102.	322.	999.	2499.														
2.7	7.86	31.2	108.	356.	1110.	3332.														
2.75	8.00	32.2	113.	369.	1110.	3332.														
2.8	8.16	33.4	118.	399.	1249.	4999.														
2.85	8.30	34.5	124.	416.	1249.	4999.														
2.9	8.46	35.6	131.	454.	1428.	4999.														
2.95	8.61	36.7	136.	475.	1428.	4999.														
3.0	8.77	37.9	144.	525.	1666.	4999.														
3.05	8.91	39.2	151.	555.	1666.	4999.														
3.1	9.07	40.5	158.	587.	1999.	9999.														
3.15	9.21	41.6	163.	587.	1999.															
3.2	9.37	42.9	171.	624.	2499.															
3.25	9.52	44.0	178.	666.	2499.															
3.3	9.67	45.5	188 .	713.	2499.															
3.35	9.82	46.8	195.	768.	2499.															
3.4	9.98	48.3	203.	832.	3332.															
3.45	10.1	49.5	212.	832.	3332.															
3.5	10.3	51.1	221.	968.	3332.															
4.0	11.8	66.1	322.	1666.	4999.															
4.5	13.3	83.0	434.	2499.	4999.															
5.0	14.9	102.	624.	3332.	9999.															
5.5	16.5	122.	832.	4999.																
6.0	18.0	146.	999.	9999.																
6.5	19.6	171.	1249.																	
7.0	21.1	199.	1666.																	
7.5	22.7	226.	1999.																	
8.0	24.3	255.	2499.																	
8.5	25.8	293.	2499.																	
9.0	27.4	322.	3332.																	
9.5	28.9	369.	3332.																	
10.0	30.5	399.	4999.																	
15.0	46.2	908.	9999.																	
20.0	61.9	1666.																		
25.0	77.1	2499.																		
30.0	93.3	3332.																		
35.0	109.	4999.																		
40.0	124.	4999.																		
45.0	140.	9999.																		
50.0	153.																			
60.0	188.																			
70.0	221.																			
80.0	249.																			
90.0	285.																			
100.0	311.																			
120.0	369.																			
140.0	434.																			
150.0	475.																			
160.0	499.																			
180.0	555.																			
200.0	624.																			
250.0	768.																			
300.0	908.																			
350.0	1110.																			
400.0	1249.																			
450.0	1428.																			
500.0	1666.																			
600.0	1999.																			
700.0	1999.																			
1000.0	3332.																			
1500.0	4999.																			
2000.0	4999.																			
3000.0	9999.																			

Z.	n=22	n=23	n=24	n=25	n=26	n=27	n=28	n=29	n=30
.1	2.07	2.11	2.15	2.18	2.22	2.26	2.29	2.33	2.37
.15	2.92	2.99	3.07	3.14	3.22	3.30	3.37	3.45	3.52
.2	4.41	4.58	4.76	4.94	5.12	5.31	5.50	5.69	5.90
.25	6.23	6.52	6.83	7.14	7.46	7.79	8.12	8.47	8.82
.3	9.89	10.5	11.2	11.9	12.7	13.5	14.3	15.2	16.1
.35	14.1	15.2	16.3	17.5	18.7	20.1	21.5	23.0	24.5
.4	23.7	26.0	28.6	31.4	34.3	37.8	41.2	45.3	49.3
.45	34.2	38.1	42.1	46.6	51.6	57.1	63.1	69.9	76.5
.5	60.7	69.4	79.0	89.9	102.	117.	132.	151.	171.
.55	89.1	103.	118.	136.	155.	181.	207.	237.	269.
.6	166.	199.	237.	277.	332.	399.	475.	555.	666.
.65	243.	302.	256.	434.	525.	624.	768.	908.	1110.
.7	475.	624.	768.	999.	1249.	1666.	1999.	2499.	3332.
.75	713.	908.	1110.	1428.	1999.	2499.	3332.	3332.	4999.
.8	1428.	1999.	2499.	3332.	4999.	9999.	9999.	9999.	9999.
.85	1999.	2499.	3332.	4999.	4999.				
.9	3332.	4999.	9999.	9999.	9999.				
.95	4999.	4999.							
1.0	9999.	9999.							

Significance of A Difference in T.C.P.A. as Calculated by STUDENT'S METHOD

Koloa Sugar Co. Exp. 28. Amounts of Nitrogen

A Plots 97 Lbs. N. B Plots 126 Lbs. N.

T.C.P.A. B Plots	T.C.P.A. A Plots	Gain of B Over A	Deviation from Mean	D	D²
44.3	44.9	— .6	+3.0		9.0
45.0	41.9	3.1	— .7		.49
41.6	44.1	—2.5	+4.9		24.01
47.1	41.2	5.9	—3.5		12.25
51.2	44.9	6.3	—3.9		15.21
55.4	53.2	2.2	+ .2		.04
					61.00

N=Total paired items 6 Sum 14.4 14.4

$$\text{Mean } \frac{14.4}{6} = 2.4 \qquad \frac{61}{6} = 10.16$$

$$\text{Standard Deviation} = \sqrt{10.16} = 3.18$$

$$Z = \frac{2.4}{3.18} = .755$$

Using the value for Z (.755) enter the column in the "Table of Odds" under Z at .75, then read across under the column n=6 (6 plots) the figure 11.8. This means that the Odds are 11.8 to 1 against such a difference (2.4 T.C.P.A.) occurring if the nitrogen applications to each plot were the same.

* From Journal of The American Society of Agronomy, Vol. 16, 1924, pp. 60-73.

Studies in Experimental Technique—Shape, Size and Replication

FROM THE 1931 HAKALAU BLANK TEST

By Ralph J. Borden

A typical area of unirrigated, first ratoon, Yellow Caledonia cane at Hakalau Plantation, which had been uniformly fertilized and handled, was harvested in one-twentieth acre, six-line plots, in order to sample the uncontrolled variation within the field, and to afford data for a statistical study to assist us in determining how such factors as plot size, shape, and replications might affect the reliability of average yields therefrom. This same area had been harvested in a similar manner, as plant cane some twenty-one months previously, and for those who are interested in noting the persistence of the natural fertility trends in our cane fields, we offer the line graphs of Fig. 1, wherein the 1931 plot yields show a distinct tendency to follow the yield curve of the 1929 plant crop.

The plan of the Hakalau Blank Test, together with information necessary to a complete comprehension of the data which follow, is shown in Fig. 2. A summary of the many individual studies that were made from the data is given in Table I. Grouping and comparisons of particular interest are discussed hereafter in some detail.

Evidence of Variation

Using the coefficient of variation (C. V.) as a measure of the amount of uncontrolled variation that exists within the members of a group of plots, we have an indication of the range of plot yields which have entered into the average yield. For instance: the twelve plots of Column I have the same average yield as the twelve plots of Column II, i.e., 71 tons. The Column I plots, however, have a coefficient of variation of 6.2, and we can therefrom conceive of two-thirds of this group of twelve plots as having yields of from 66.6 to 75.4 tons.* The twelve plots of Column II have a C. V. of 10.6; hence we picture two-thirds or nine of these plots with yields which are between 63.5 and 78.5 tons,† thus a wider range of variation than exists between the plots in Column 1. Hence the average yield of 71 tons for the twelve plots of Column I is a more reliable figure than the 71-ton average for the Column II plots, since the range of plot yields which enter into it is not so wide.

Examination of the data in Table I shows a considerable difference in the range of variation that exists in the area harvested. The two center Columns, II and III, show considerably more variation than Columns I or IV. In Section 1, which borders the government road, we find the least variation of any of the groups of twelve plots, while Section 4, which borders the railroad track, appears from its C. V. of 9.27 to be somewhat more spotty. The twenty-four plots in each of the horizontal divisions, 1 and 2, show less variability than those in the vertical divisions, 3 and 4.

* 71 tons ± 6.2% which is 71 tons ±4.4 tons or 66.6 to 75.4 tons.

† 71 tons ±10.6% which is 71 tons ±7.5 tons or 63.5 to 78.5 tons.

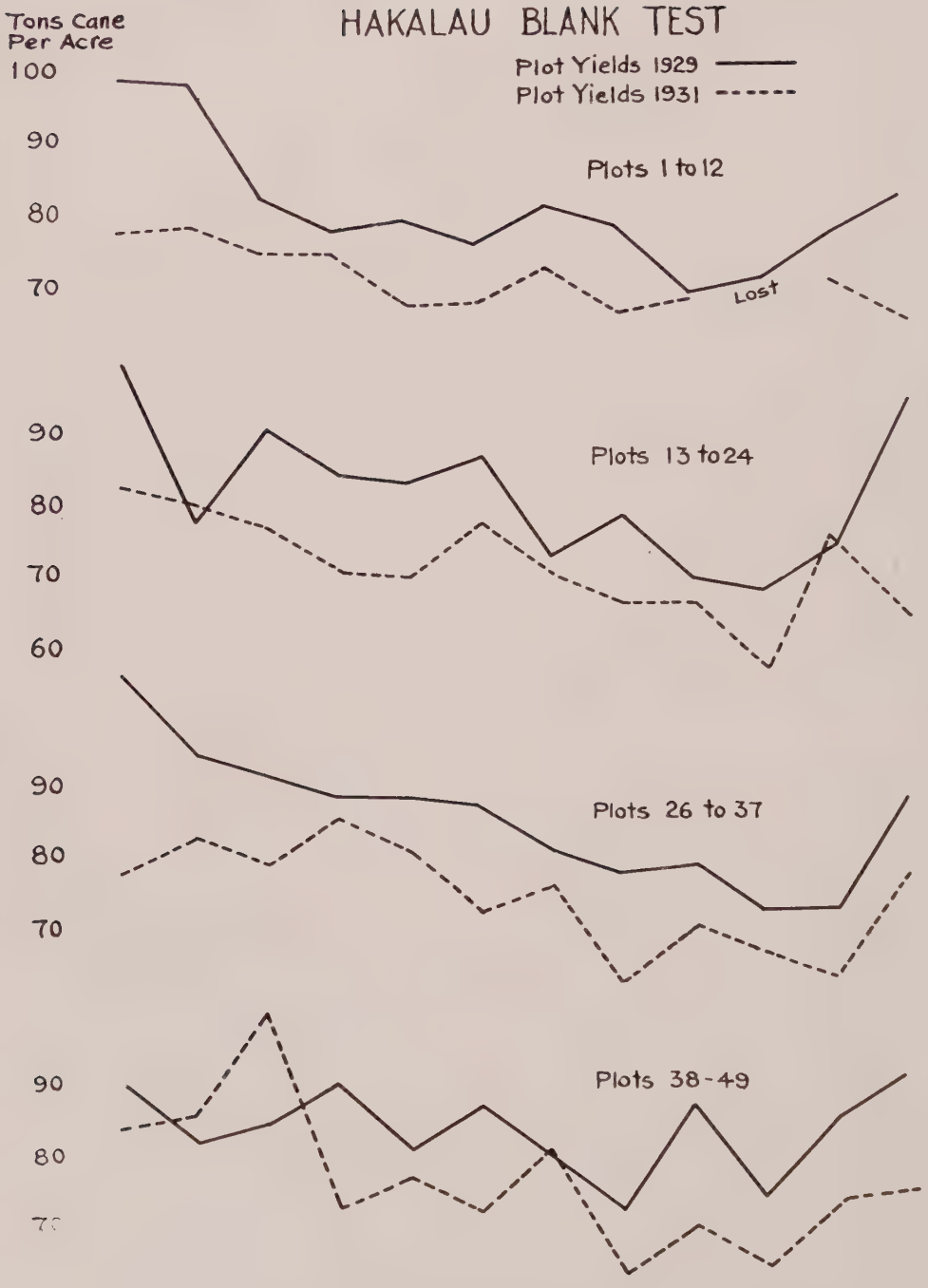

HAKALAU BLANK TEST
Tons Cane Per Acre
Plot Yields 1929
Plot Yields 1931
100
90
80
70
Plots 1 to 12
Lost
90
80
70
60
Plots 13 to 24
90
80
70
Plots 26 to 37
90
80
Plots 38-49

Fig. 1.

Layout of Hakalau Blank Test - 1931
Showing plot numbers and yields (T.C.A.).
Plots are 35' X 62' or $\frac{1}{20}$ acre.

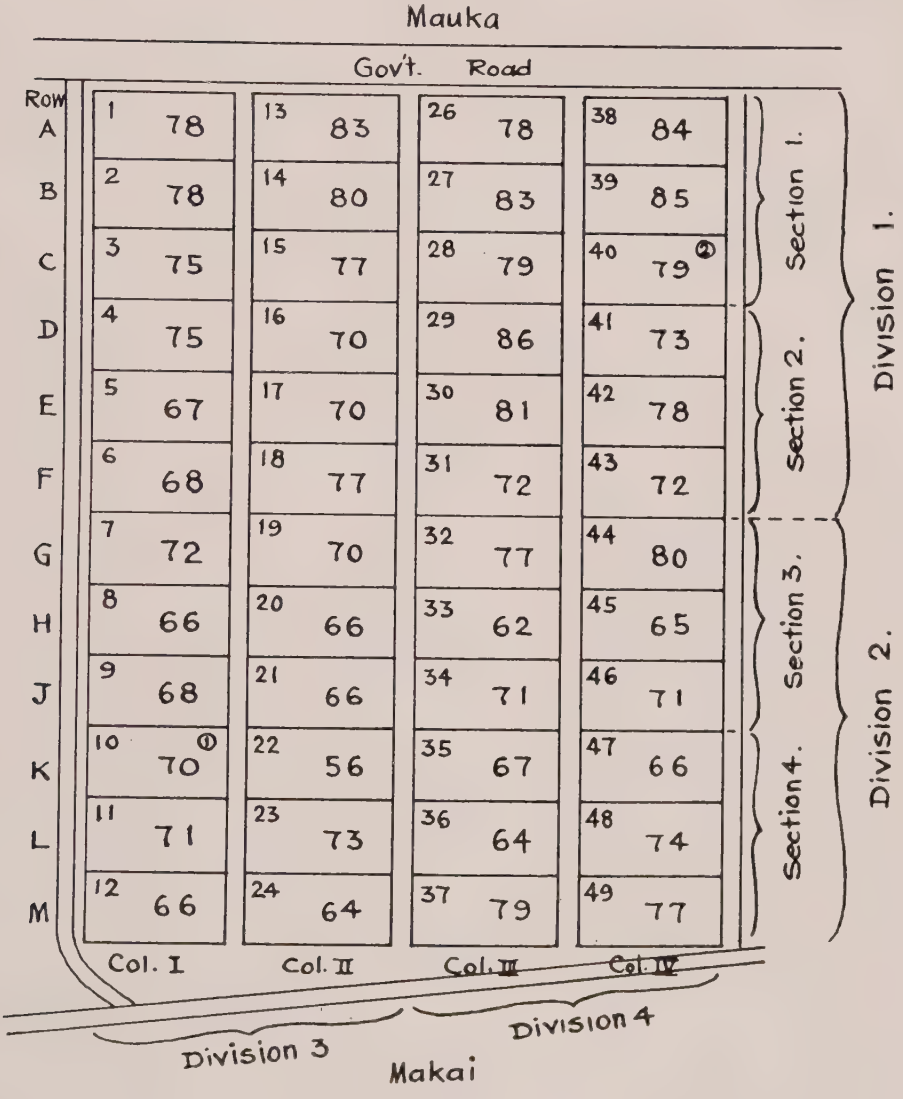


Fig. 2.

The method of dividing the area into segments for this study is shown to assist in identifying references to the various groups that are compared.

(1) The yield of this plot was lost. For this study it has been assumed as the average of the two plots on either side.

(2) The reported yield of this plot, 102 tons, is obviously in error. For this study it has been assumed as the average of the plots which adjoin it.

Table I

Summary of Individual Studies

Location or Identity of Plots Used (*)	Size of Plots	Average Yield Per Cent	C. V. or Per Cent S. D.	Number of Plots	Per Cent PEm
Sec. 1	35′ x 62′	80	3.88	12	0.76
Sec. 2	"	74	7.56	12	1.47
Sec. 3	"	70	7.42	12	1.45
Sec. 4	"	69	9.27	12	1.80
Col. I	35′ x 62′	71	6.2	12	1.18
Col. II	"	71	10.6	12	2.06
Col. III	"	75	10.2	12	1.98
Col. IV	"	75	8.5	12	1.65
Div. 1	35′ x 124′	77	6.10	12	1.18
Div. 2	"	70	7.35	12	1.42
Div. 3	"	71	7.75	12	1.52
Div. 4	"	75	8.60	12	1.67
Div. 1	70′ x 62′	77	6.20	12	1.20
Div. 2	"	70	4.90	12	0.92
Div. 3	"	71	7.74	12	1.51
Div. 4	"	75	7.00	12	1.36
All	35′ x 248′	73	7.47	12	1.45
"	70′ x 124′	73	7.35	12	1.42
"	140′ x 62′	73	6.92	12	1.35
Div. 1	35′ x 62′	77	6.95	24	0.96
Secs. 2 and 3	"	72	8.02	24	1.10
Div. 2	"	69	8.38	24	1.15
Div. 3	35′ x 62′	71	8.53	24	1.17
Cols. II and III	"	73	10.55	24	1.45
Div. 4	"	75	9.20	24	1.26
All	35′ x 124′	73	8.50	24	1.20
"	70′ x 62′	73	7.77	24	1.07
Secs. 1, 2, and 3	35′ x 62′	75	8.45	36	0.95
Secs. 2, 3, and 4	"	71	8.52	36	0.96
Cols. I, II & III	35′ x 62′	72	9.42	36	1.06
Cols. II, III & IV	"	74	9.58	36	1.08
All	35′ x 62′	73	9.20	48	0.90
All	105′ x 124′	73	7.15	8	1.70
"	210′ x 62′	73	6.65	8	1.55
"	70′ x 248′	73	7.02	6	1.93
"	140′ x 124′	73	7.00	6	1.93
"	105′ x 248′	73	7.00	4	2.36
"	210′ x 124′	73	6.95	4	2.35
"	420′ x 62′	73	3.20	4	1.08
"	140′ x 248′	73	7.10	3	2.74
"	210′ x 248′	73	7.55	2	3.62
"	420′ x 124′	73	3.90	2	1.86

(*) See layout, Fig. 2.

Shape

The longer, narrow plots (35′x124′) in Divisions 1 and 3, are no more variable than the squarer plots (70′x62′) in these same divisions, but Divisions 2 and 4 carry indications which point to a greater similarity between the squarer plots.

There appears to be less variation on the flume side of the field than on the opposite side, but the spot variation of the center columns is confusing. The direction of greatest variation, however, is from the mauka to the makai end of the test area, and we would therefore expect greater similarity within the group of plots whose long axes extend in the direction of this greater variation and which are laid out (across the field) at right angles to it. That we do find this condition is evident from the fact that when we divide the whole area into the same number of various shaped plots of a similar acreage, we have coefficients of variation as shown in Table II.

Table II

Showing Coefficients of Variation for Plots of Various Shapes

	C. V.	No. of Plots	Area	Shape (Width x Length)	Description
A.	8.50	24	.1 ac.	35′ x 124′	Long plot axis at right angles to greatest variation.
	7.77	24	"	70′ x 62′	Long plot axis parallel to greatest variation.
B.	7.47	12	.2 ac	35′ x 248′	Long axis at right angles.
	7.35	12	"	70′ x 124′	" " " " "
	6.92	12	"	140′ x 62′	" " parallel.
C.	7.15	8	.3 ac	105′ x 124′	Long axis at right angles.
	6.65	8	"	210′ x 62′	" " parallel.
D.	7.02	6	.4 ac	70′ x 248′	Long axis at right angles.
	7.00	6	"	140 x 124′	" " parallel.
E.	7.00	4	.6 ac	105′ x 248′	Long axis at right angles.
	6.95	4	"	210′ x 124′	" " " " "
	3.20	4	"	420′ x 62′	" " parallel.
F.	7.55	2	1.2 ac	210′ x 248′	Long axis at right angles.
	3.90	2	"	420′ x 124′	" " parallel.

Size of Plot

Our interest in plot size, springs from a desire to learn how the uncontrolled variation that exists in field experiments can be lessened to an extent that will allow us to compare purposeful introduced variates under the greatest similarity of conditions. Will large plots or small plots give us this greater uniformity?

In Table III, there is presented a summary of the separate comparisons

that were made to determine how an increased plot size would affect the coefficient of variation of various groupings that might naturally be made in the test area. For each comparison, we have used the same number (12) of plots, and were one group of comparisons did not occupy the whole of the experimental field, we have averaged the C. V.'s for separate groups sufficient to cover the whole area, and presented this average with its probable error. Hence our figures should at least be indicative, since every plot in the test area is represented in the amount of C. V. listed for each grouping of various sized (and shaped) plots.

TABLE III

SHOWING COEFFICIENTS OF VARIATION FOR PLOTS OF VARIOUS SIZES

(All forty-eight plots used in each grouping; twelve units for each comparison)

Group	No. of Comparisons	Identity and Description	Size	C. V.
1	4	Single plots, in columns	.05 ac.	8.90 ±.20
2 (a)	2	Double plots, end to end, in columns	.1 ac	8.18 ±.29
2 (b)	2	Double plots, side by side, in columns	.1 ac	7.37 ±.25
3 (a)	1	Quadruple plots, end to end, total area	.2 ac	7.47
3 (b)	1	Quadruple plots, side by side, total area	.2 ac	6.92
3 (c)	1	Quadruple plots, in a 2x2 block, total area	.2 ac	7.35
4 (a)	2	Double plots, end to end, in sections	.1 ac	6.73 ±.42
4 (b)	2	Double plots, side by side, in sections	.1 ac	5.55 ±.44
5	4	Single plots, in sections	.05 ac	7.03 ±.74

Comparing the groupings that were made in the columns, we apparently have quite definite evidence that the variation within the groups of plots decreases as their size is increased. This same decrease with larger plot size is not so apparent from the C. V. of the groupings of the sections. Perhaps this is what we should expect to find, since we have already noted the greater variability within the columns than within the sections. The larger plot size has evidently smoothed out the greater differences and lessened their effect upon the variability of the individual plot yields.

Within an area which shows quite general uniformity, in so far as field conditions can be uniform, there seems nothing to be gained by increasing the plot size. The twenty-four single plots in Division I have a C. V. of 6.95. Increasing their size from 35′x62′ to 35′x124′ results in an increased C. V. for the twenty-four larger plots, to 8.5; increasing their size to 70′x62′ also results in a larger coefficient of variation (7.77).

Specifically, we show in Table IV, eight instances taken from our data, in which twelve single-unit (35′x62′) plots are first doubled and then quadrupled in size. The change in the coefficient of variation of these blocks of twelve plots, shows how the increase in the individual plot sizes has affected the variability within them. The many exceptions wherein the greater size has failed to reduce the coefficient of variation, make it necessary for us to be exceedingly cautious in recommending large plots for field experiments, without having rather definite knowledge of the field variation which exists in the area wherein the test is to be installed.

Table IV

Showing How an Increase in the Size of Plot May Affect the Coefficient of Variation

No. of Plots	Size	Location	C. V.	No. of Plots	Size	Location	C. V.
12	35′x′62	Column I	6.20	12	35′x62′	Section 1	3.88
12	35′x124′	Division 3	7.75*	12	35′x124′	Division 1	6.10*
12	35′x248′	All	7.47	12	35′x248′	All	7.47*
12	35′x62′	Column IV	8.50	12	35′x62′	Section 4	9.27
12	35′x124′	Division 4	8.60*	12	35′x124′	Division 2	7.35
12	35′x248′	All	7.47	12	35′x248′	All	7.47*
12	35′x62′	Column I	6.20	12	35′x62′	Section 1	3.88
12	70′x62′	Division 3	7.74*	12	70′x62′	Division 1	6.20*
12	140′x62′	All	6.92	12	140′x62′	All	6.92*
12	35′x62′	Column IV	8.50	12	35′x62′	Section 4	9.27
12	70′x62′	Division 4	7.00	12	70′x62′	Division 2	4.90
12	140′x62′	All	6.92	12	140′x62′	All	6.92*

* The increased size has also increased the variation in these cases.

Replication

The individual plot in a field experiment is a sample. It has become a common tendency to replicate our plot treatments and present the average yield of similarly grown samples for the guidance of plantation practices. It should become a more common practice to furnish a measure of the accuracy of such averages by furnishing the probable error of the mean (PEm) with any average which is so submitted.

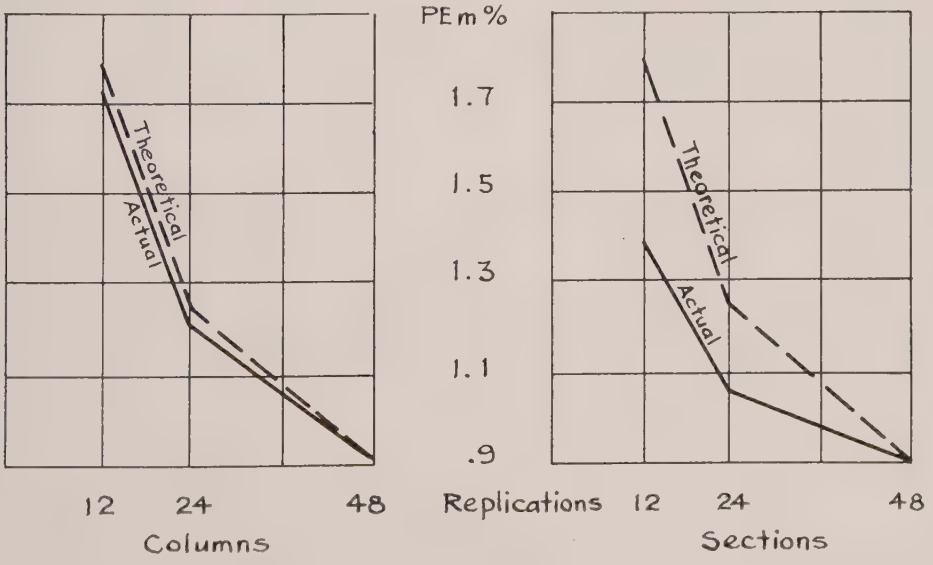


Fig. 3. Showing how an increase in the number of replications has reduced the probable error of the mean.

Our chief interest in the matter of plot replication lies in the fact that theoretically, a reduction in the probable error of a mean yield can be expected to occur in proportion to the square root of the number of plots or samples used. Hence an average yield from a larger number of samples should be a more reliable figure than an average yield from a smaller number. Considered as measures of reliability therefore, the lower PEm figures indicate greater accuracy.

The probable error for any single plot in this area is 6.21 per cent. In Table V and Fig. 3, we have presented the theoretically expected, and the actual reductions in error which have occurred as the number of plots was increased.

TABLE V

Plot Size	Identity	No. of Replications	Theoretical * PEm Per Cent	Actual PEm Per Cent
.05 ac.	Columns	12	1.81	1.72 ±.23
"	"	24	1.27	1.22 ±.03
"	"	48	.90	.90
"	Sections	12	1.81	1.37 ±.25
"	"	24	1.27	1.06 ±.06
"	"	48	.90	.90

* $\frac{PEs}{\sqrt{n}}$ or $\frac{6.21}{\sqrt{n}}$

More specifically, however, our interest lies in studying the effect on the PEm when a natural grouping is increased to provide more replications. We offer several instances of this sort in Table VI.

TABLE VI

SHOWING THE EFFECT ON THE PEM OF INCREASING THE TOTAL NUMBER OF ONE-TWENTIETH ACRE PLOTS, TO PROVIDE FOR MORE REPLICATIONS

	Original 12 One-twentieth Acre Plots		Increased To 24 Plots		Increased To 36 Plots		Increased To 48 Plots	
	Location	PEm%	Location	PEm%	Location	PEm%	Location	PEm%
1.	Col. 1	1.18	Col. I & II	1.17	Col. I, II & III	1.06	All 4 Col.	.90
2.	Col. IV	1.65	Col. IV & III	1.26	Col. IV, III, II	1.08	All 4 Col.	.90
3.	Sec. 4	1.80	Sec. 4 & 3	1.15	Sec. 4, 3, 2	.96	All 4 Sec.	.90
4.	Sec. 1†	.76	Sec. 1 & 2	.96	Sec. 1, 2, 3	.95	All 4 Sec.	.90
5.	(a) Sec. 3	1.45	Sec. 3 & 2	1.10	Sec. 3, 2, 1	.95	All 4 Sec.	.90
	(b) "	1.45	Sec. 3 & 4	1.15	Sec. 2, 3, 4	.96	All 4 Sec.	.90
6.	(a) Sec. 2	1.47	Sec. 2 & 3	1.10	Sec. 2, 3, 4	.96	All 4 Sec.	.90
	(b) "	1.47	Sec. 2 & 1	.96	Sec. 3, 2, 1	.95	All 4 Sec.	.90
7.	(a) Col. II	2.06	Col. II & III	1.45	Col. II, III & IV	1.08	All 4 Col.	.90
	(b) "	2.06	Col. II & I	1.17	Col. III, II & I	1.06	All 4 Col.	.90
8.	(a) Col. III	1.98	Col. III & II	1.45	Col. III, II & I	1.06	All 4 Col.	.90
	(b) "	1.98	Col. III & IV	1.26	Col. II, III & IV	1.08	All 4 Col.	.90

PRACTICAL APPLICATION

In order to make a practical application of the data obtained in this study, let us assume that we are to test three variates and have selected this field upon which

† The increase in number of plots has not reduced the PEm in this case.

to install our layout. Starting with the row of plots at the government road, or at the flume, we have several natural alternatives which have been grouped in Tables VII and VIII to show how the relationships between size, shape and the number of replications which we might arbitrarily decide upon, would affect the probable error of the mean and hence the reliability of our average yield results.

Table VII

Showing the Relationship Between Size, Shape and Number of Replications, and How These Factors Would Affect the PEm Yield of Three Variates Installed, on the Hakalau Blank Test Layout, **from the Government Road.**

Location	Assumed Variates	Total Area Used	Plot Size	Plot Shape (WxL)	No. of Replications	Per Cent PEm
1. a. Sec. 1	3	.6 ac.	.05 ac.	35′ x 62′	4	1.31
b. Div. 1	3	1.2 ac.	.1 ac.	35′ x 124′	4	2.06
c. All plots	3	2.4 ac.	.2 ac.	35′ x 248′	4	2.52
2. a. Sec. 1	3	.6 ac.	.05 ac.	35′ x 62′	4	1.31
b. Div. 1	3	1.2 ac.	.1 ac.	70′ x 62′	4	2.09
c. All plots	3	2.4 ac.	.2 ac.	140′ x 62′	4	2.33
3. a. Sec. 1 & 2	3	1.2 ac.	.05 ac.	35′ x 62′	8	1.66
b. All plots	3	2.4 ac.	.1 ac.	35′ x 124′	8	2.01
c. All plots	3	2.4 ac.	.1 ac.	70′ x 62′	8	1.85
4. a. Sec. 1	3	.6 ac.	.05 ac.	35′ x 62′	4	1.31
b. Sec. 1 & 2	3	1.2 ac.	.05 ac.	35′ x 62′	8	1.66
c. Sec. 1, 2, 3	3	1.8 ac.	.05 ac.	35′ x 62′	12	1.65
d. All 4 Sec.	3	2.4 ac.	.05 ac.	35′ x 62′	16	1.55

Table VIII

Showing the Relationship Between Size, Shape and Number of Replications, and How These Factors Would Affect the PEm Yield of Three Variates Installed on the Hakalau Blank Test Layout, **from the Flume.**

Location	Variates	TotalArea Used	Plot Size	Plot Shape	No. of Replications	Per Cent PEm
1. a. Col. I	3	.6 ac.	.05 ac.	35′ x 62′	4	2.09
b. Div. 3	3	1.2 ac.	.1 ac.	35′ x 124′	4	2.61
c. All plots	3	2.4 ac.	.2 ac.	35′ x 248′	4	2.52
2. a. Col. I	3	.6 ac.	.05 ac.	35′ x 62′	4	2.09
b. Div. 3	3	1.2 ac.	.1 ac.	70′ x 62′	4	2.60
c. All plots	3	2.4 ac.	.2 ac.	140′ x 62′	4	2.33
3. a. Col. I & II	3	1.2 ac.	.05 ac.	35′ x 62′	8	2.03
b. All plots	3	2.4 ac.	.1 ac.	35′ x 124′	8	2.01
c. All plots	3	2.4 ac.	.1 ac.	70′ x 62′	8	1.85
4. a. Col. I	3	.6 ac.	.05 ac.	35′ x 62′	4	2.09
b. Col. I & II	3	1.2 ac.	.05 ac.	35′ x 62′	8	2.03
c. Col. I, II & III	3	1.8 ac.	.05 ac.	35′ x 62′	12	1.83
d. All 4 Col.	3	2.4 ac.	.05 ac.	35′ x 62′	16	1.55

We have previously noted that the variation in any layout, starting from the government road, would be increased with any procedure, large plots or added replications, which would extend it into the more variable conditions at the makai end of the test area. The comparisons offered in Table VII amply illustrate this fact, and in the cases cited, *because we know of this variability,* we are not surprised that the reliability of our mean yields was not always increased (as indicated by a lowered PEm), where we had expected it to be.

From Table VIII, we note that where the extension of the total area for larger or more plots was across the direction of greatest variation, the increase in the number of replications was effective in slightly increasing the reliability of the average yield for the three assumed variates.

Summary

The uncontrolled variation within the area occupied by the Hakalau Blank Test has been determined and located.

The effect of altering the size and the shape of plots in order to secure greater similarity and uniformity for testing cane field problems has been studied.

The manner in which an increase in the number of plot replications, in a cane field, may or may not decrease the probable error and thus enhance the accuracy of their mean yield, has been pointed out.

Specific and practical applications of the statistical data have been made to illustrate how various changes can affect the reliability of average yields.

Generalization or recommendation, as to the best size or shape of plot, or with respect to the optimum number of replications that should be included in field tests from which the average yields of the various treatments are to be reported for plantation guidance, would be dangerous. *Only when we quite definitely know the nature and extent of the variation that exists in the area where we propose to install a field experiment, can we safely recommend that plan and layout which will give reliable guidance from average yields obtained.*

Some Mononchs of Hawaii

By Gertrude Cassidy

The soils of our cane fields—hitherto a biological terra incognita to most of us—give surprisingly interesting results when an attempt is made to determine their biological population.

Millions of inhabitants, many of microscopic dimensions, pursue their countless activities in the soil under our feet and collect in large and flourishing colonies around the roots of our sugar cane. Myriads of bacteria, protozoa, nematodes, annelid worms, insects and arachnids are present in our soils, and may be readily found upon microscopic examination.

Preliminary studies with relation to nematode infestation have led to the collection and preservation of representative soil samples from the cane-producing islands of Hawaii. Up to the present only a limited number of samples has been available and the species here recorded were obtained from a total of forty samples of soil.

A series of soil population counts have been undertaken to determine the nematode population of representative cane areas. These have been found to vary with the locality, type of soil, elevation and crop history, and result in numbers ranging anywhere from one to twenty billion nematodes per acre foot of soil. Of this vast population many genera and a large number of unrecorded species are present. An effort is being made to collect and identify these unrecorded species to enable us to interpret the significance of their presence around the roots of the cane. At the present time it is estimated that we have about 30 different genera, while the species range between 100 to 200 or more in number.

Formerly in our work it has been customary to divide the nematodes into three groups for convenience of description:

(1) The plant-destructive, spear-bearing nematodes which give rise to primary root damage.

(2) The plant-destructive nematodes which give rise to secondary root damage.

(3) The non-phytophagous nematodes.

Of these three groups, the first has received most of our attention and observations have been largely limited to the work of the root infesting Tylenchus. To date we are aware of five Tylenchus species in our sugar cane, the most widespread and active being *Tylenchus similis* which has been recognized in cane for over twenty years and is now found in more than half of our Hawaiian crop. Detailed root counts vary according to the severity of the infestation, the maximum count at present being 2532 Tylenchus nemas per linear inch of cane root.

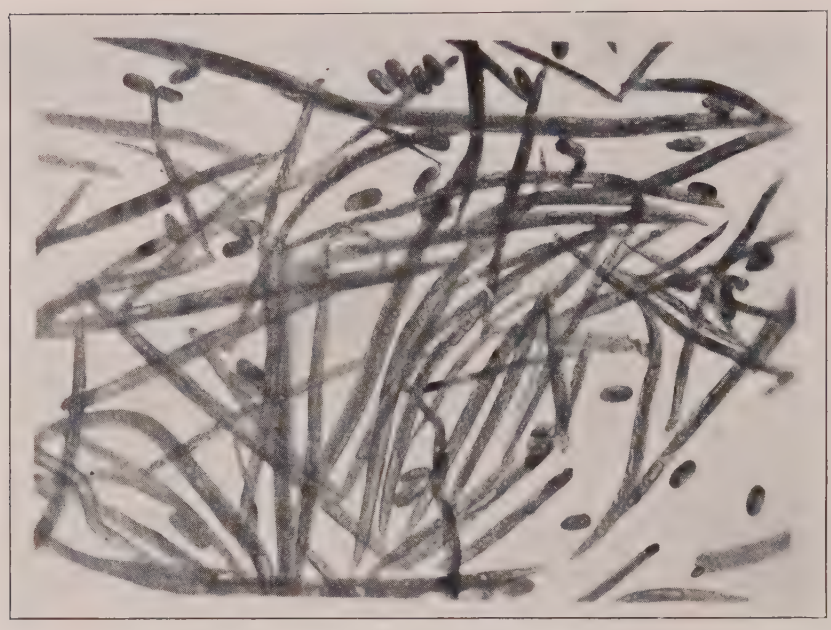


Fig. 1. *Tylenchus similis*, adults, larvae and eggs as they appear upon dissecting an infested cane root. In this case one linear inch of infested root (P. O. J. 36 plant cane) was found to contain 2532 nemas. Photograph by C. W. Carpenter.

The following photographs (Figs. 2-3) demonstrate the differences in development noted in two sugar cane seedlings of the same variety and age. Fig. 2 represents a check seedling grown in soil sterilized by heating; Fig. 3, a Tylenchus-infested seedling grown under identical conditions and photographed 60 days after making the nematode inoculation.

Further studies are to be made to determine what part, if any, of the root damage is caused by organisms associated with the nematodes, and to ascertain, if possible, to what extent the activities of Tylenchus are influenced by the sterilization of the soil.

In general characters the two cane photographs (Figs. 2 and 3) resemble those of the Tylenchus-infested coffee plant, together with the check plant, illustrated in Fig. 4, which were the result of observations of Tylenchus damage in coffee, made by Dr. W. Bally, Proefstation, Malang, Java.

While all three groups are of importance in their relation to sugar cane, it was considered appropriate at this stage to devote some time to the study and identification of certain members of the third group—the non-phytophagous nematodes.

This group includes the predacious genus Mononchus (Bastian 1866) and it is with these nematodes that we are primarily concerned. For many years Mononchus, together with other genera found intimately associated with growing roots, was accepted as a plant-injurious nematode. This assumption was a natural one owing to the fact that specimens were seldom, if ever, observed alive so that their feeding habits did not come under observation. Through the researches of Cobb Steiner, Menzel and Heinly, this view has been disproved, and it is now an established fact that Mononchus is non-phytophagous and that, by reason of its predacious habit, it must be considered as a favorable factor in nematode control.

Fig. 2. Cane seedling (D 1135 x H 456) aged 4½ months. Control plant.

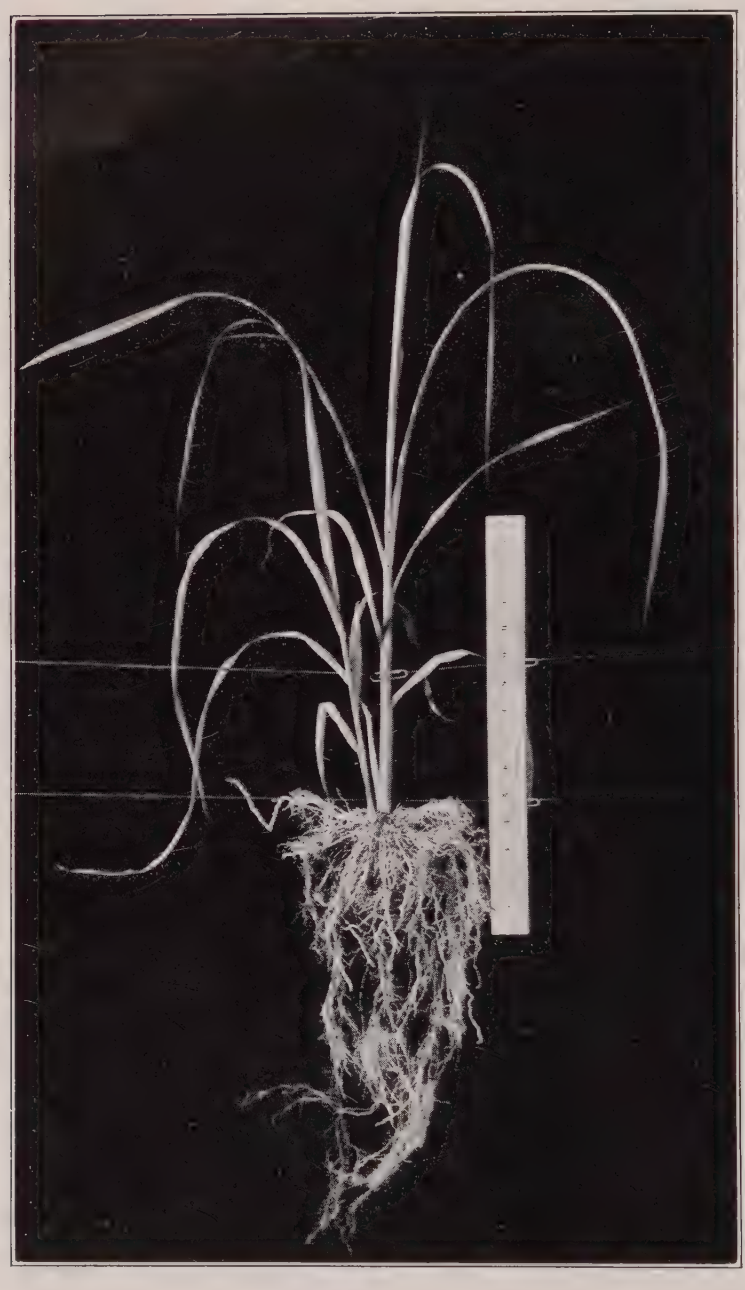


Fig. 3. Cane seedling (D 1135 x H 456) aged 4½ months, inoculated with a culture of *Tylenchus similis*. Inoculation period 60 days.

Fig. 4. Effects of Tylenchus in coffee plants. (Malang, Java.) Control plant on left. Nematode-infested plant on right. Photograph by courtesy of Dr. W. Bally, Proefstation Malang.

Soil examinations conducted during the past year show that certain species of Mononchus are present in the cane fields of Oahu, Hawaii, Maui and Kauai. The percentage population varies enormously with the location and as yet generalizations cannot be made as to the incidence of Mononchus in the field. From the limited number of examinations already completed it would appear that Mononchus is present in about 50 per cent of the cane fields. The population presents a wide range of difference in the various locations—in some only an occasional specimen being present, while in others, the counts rise to millions of Mononchus per acre.

The distribution of identified Mononchus species up to the present time is as follows:

Oahu—

Mononchus brachylaimus, Cobb, 1917.
Mononchus brachyuris, Bütschlii, 1873.
Mononchus lacustris, Cobb, 1915.
Mononchus longicaudatus, Cobb, 1893.
Mononchus hawaiiensis n. sp.
Mononchus papillatus, Bastian, 1866.
Mononchus sigmaturus, Cobb, 1917.

Hawaii—

Mononchus brachylaimus, Cobb, 1917.
Mononchus brachyuris, Bütschlii, 1873.
Mononchus index, Cobb, 1907.
Mononchus longicaudatus, Cobb, 1893.
Mononchus parvus, de Man, 1879.

Maui—

Mononchus brachyuris, Bütschlii, 1873.
Mononchus cobbi, n. sp.
Mononchus lacustris, Cobb, 1915.
Mononchus muscorum (Dujardin), Bastian, 1866.
Mononchus papillatus, Bastian, 1866.
Mononchus parvus, de Man, 1879.

Kauai—

Mononchus lacustris, Cobb, 1915.
Mononchus papillatus, Bastian, 1866.

This list of species is encouraging as it includes several of the most voracious and therefore most desirable Mononchus species known.

The experimental work of Steiner and Heinly, completed in 1922, proved conclusively that Mononchus is a natural factor worthy of consideration in the problem of nematode control.

The species cultivated by these workers was *Mononchus papillatus*, a cosmopolitan species well known for its voracity. This species is well established in certain localities of Oahu, Maui and Kauai and so the experimental findings of Steiner and Heinly may be utilized in our interest.

Laboratory cultures were made by these workers and observed over a period of several months (December-May). Various culture media were employed but finally it was found that the most favorable conditions were produced when a mixture of soil and water was used.

During this time the feeding habits of *Mononchus papillatus* were closely watched and one individual of this species was observed over a period of 12 weeks to devour a total of 1332 nematodes.

On this subject Steiner and Heinly report as follows:

> Our records showed that the number of nematodes killed daily increased as the mononch developed, beginning with one or two destroyed during the third or fourth day of larval life, and attaining a maximal number of sixty-five. In one case as many as eighty-three *Heterodera radicicola* were killed (either swallowed wholly or partly sucked out) by one mononch in one day. The largest amount of food was consumed at the time the maximal number of eggs was produced, and then it decreased during the senile stage of life. During a lifetime of about twelve weeks one animal killed 1332 nematodes. We are certain that this number may be very much larger under natural conditions. It was also observed that during the moulting periods fewer nematodes were killed and for a period of one or two days none at all, with a decided increase after the moult. . . .
>
> Judging from the behavior of *M. papillatus*, the organs of touch were probably the only ones used while hunting for food. The nema moved through the medium, continually searching its surroundings by moving the head end in all possible directions. The head end contains the chief organs of touch, as well as those for chemical perception. After long observations, we came to the conclusion that *M. papillatus* was not able to find its prey at long distance, and the use of the sense organs of touch seemed to be its chief method of locating food. We could therefore confirm statements made by Menzel about this matter.
>
> As soon as the head end of a mononch came into contact with its prey, it grasped it tightly. By a sucking movement, probably of the oesophageal muscles, the head was fixed

to the prey. The nematode caught by the mononch naturally made most violent efforts to get free, and often the mononch was shaken and dragged along. But it held on tightly and soon its tooth and other mouth parts began to work. By a sucking movement of the oesophagus and mouth cavity, the mononch became more firmly fixed to its prey, when the tooth located on the dorsal wall was protruded and produced an opening in the skin of the victim. Then a stronger (or further) sucking action was exerted by the mononch and the tooth came back to its normal position. The whole oesophagus came often into action and moved forward and backward with the intestine, the whole body going through the same movements; first the body fluid of the prey was sucked out, and as this happened its body became shrunken. Very often the mononch was satisfied with this, and set free its prey, which died shortly afterwards. . . .

MONONCHUS PAPILLATUS AS A FACTOR IN FIGHTING NEMATODE PESTS

The foregoing experimental results show conclusively the predatory nature of *Mononchus papillatus*. From our experiments, and from observations made by other investigators, all kinds of nematode species, and Rotifers, Naididae (small Oligochaetes), etc., are taken as food. *Heterodera radicicola* is acceptable in large numbers, and we were able to rear *M. papillatus* by feeding this form of plant-injurious nema exclusively. The same thing happens in the soil and there is no doubt but that mononchs live there in about the same way as in our cultures. Undoubtedly this predatory nema when present kills *Heterodera* and other injurious forms in soil planted with crops. It is therefore extremely useful and its propagation should be encouraged. Under some conditions this form perhaps completely controls *Heterodera* and similar plant-injurious species. Why should this not become the case in our infested fields? Further investigations should be started along these lines.

Once in the roots, *Heterodera* and other such root-parasites are probably protected against the predatory mononchs, but when moving freely in the soil during larval life, they may be destroyed in large numbers and we are convinced that under favorable conditions *Mononchus* is able partially, perhaps completely to control some of these destructive forms. In order to advance any further along this line, it is absolutely necessary to have a knowledge of the nematode population of different kinds of soil, of the relationships that exist between these forms and other members of the community of living forms that exist there, and of their relationships to other nematode species.

THE SOIL, ITS LIFE AND THE NUMBER OF NEMATODES, ESPECIALLY OF PREDATORY FORMS THEREIN

Our knowledge of life in the soil, especially of microscopic life there, is still very restricted. We know very little about the relationships that exist between the living components of the soil, and often we do not even know these components. Certainly soil fertility does not depend entirely upon its chemical, colloidal and physical nature, but also and probably largely, upon the animal and plant life therein. The importance of soil bacteria is already known and there exists a close relationship between these bacteria and the nematode population, as a large number of nemas are bacteria consumers. Investigations carried on throughout more recent years have definitely proved that the soil contains an enormous number of nematodes, and that, next to bacteria, they form probably the largest constituent element in subterranean life.

Preliminary Observations on Cultured Mononchs

While it has not yet been possible to undertake detailed laboratory experiments with the Hawaiian species, preliminary observations have been made on two species (*Mononchus sigmaturus* and *Mononchus brachylaimus*) incidental to the collection and identification of the Hawaiian nemas:

(A). *Mononchus sigmaturus* was selected for observation as this is the species most commonly found in the cane fields of Oahu and a supply of fresh material was readily available. Cultures were prepared in (1) sterile water, (2) tap water, and (3) tap water and soil, and were kept in a moist chamber and the media changed daily.

After 24 hours culture (1) showed that ten *Mononchus sigmaturus* had devoured only eight of the nematodes supplied. The eight nemas which had been devoured were specimens of *Tylenchus similis* and *Heterodera radicicola.* The nemas which had escaped the Mononchus were very actively moving Rhabditis species. It was concluded from this and later observations that such forms as these escape the slower moving *Mononchus sigmaturus* by reason of the amazing rapidity of movement which certain Rhabditis species exhibit.

The *Mononchus sigmaturus* specimens did not appear to be favorably situated and were consistently sluggish in their movements from the first day of culture.

Never more than one or two victims were devoured within 24 hours by one of these *Mononchus sigmaturus* specimens and after the fourth day in culture the mononchs were outstretched and motionless and did not revive. The specimens were watched carefully but no eggs were deposited by this species during captivity.

Cultures (2) made in tap water, and (3) made of soil and water proved wholly unsatisfactory with this species. Within 24 hours heavy bacterial infection had occurred and further observations could not be made as the infected nematodes remained outstretched and could not be revived.

(B). A number of specimens of *Mononchus brachylaimus* were obtained from cane fields in Hawaii and used in culture for laboratory observation.

Cultures were made in (1) sterile water, (2) tap water, and (3) tap water and soil, and were kept in a moist chamber at room temperature and changed daily.

It was found that *Mononchus brachylaimus* responded equally satisfactorily to all three media and appeared highly resistant to bacterial contamination.

During the first 3-5 days of their captivity, specimens of *Mononchus brachylaimus* were noted to be extremely active and to attack and devour numbers of the nematodes added to the culture for their consumption.

Gradually they became more sluggish in their movements and would remain inert for long periods until transferred to a fresh medium 24 hours later. The number of nematodes devoured by *Mononchus brachylaimus* under these conditions was found to vary quite considerably.

At the beginning of cultivation, the mononchs were actively moving and in excellent condition. A number of observations were made to determine the daily quota of nematodes consumed by these mononchs but no definite estimate was arrived at.

It appeared that the voracity of the mononchs was appreciably influenced by their environment, and the abnormality of the situation in which they found themselves was amply demonstrated by their unfavorable reaction.

For instance, one culture of ten *Mononchus brachylaimus* observed to devour nematodes at the rate of ten per hour, was soon reduced to a pitiful two or three victims daily. As their appetite decreased so also did their other activities and

after a few days the cultured mononchs could be seen lying idly, regardless of the tempting food supplies at their disposal.

Observations made over a period of 12 weeks on a water culture containing one male and one female *Mononchus brachylaimus,* serves to demonstrate the variability of the devouring capacity of these nematodes in captivity.

First day in culture	10 nemas devoured (Tylenchus and Heterodera)
Second day in culture	8 nemas devoured " "
Third day in culture	6 nemas devoured " "
Fourth day in culture	1 nema and 74 eggs devoured (Heterodera)
Fifth day in culture	50 eggs devoured (Heterodera)
Sixth day in culture	4 nemas devoured (Heterodera)

After the fourth week in the culture medium the nemas were inert and listless and utterly disinterested in the food supplied. At most, one or two nemas were eaten and most frequently none at all. After the seventy-first day the male *Mononchus brachylaimus* died and was removed. The female continued to live until the eightieth day when she died also.

Eggs were deposited during the first three days of captivity but after that period no further deposition was observed. The earlier manifestations of physical activity, voracity and egg deposition must be accepted as more closely approaching the normal than the later less active condition.

Judging from the unusually strong pharyngeal musculature and the fact that a large percentage of all examined specimens commonly contain portions of ingested nematodes, it would appear that we are dealing with a species of unquestioned voracity.

There are several points in favor of *Mononchus brachylaimus* as a desirable species for cultivation with a view to field distribution:

(1) *Mononchus brachylaimus* is especially desirable from the standpoint of the worker as it is readily distinguished and easy to handle by reason of its usually large size (3-4 mm.).

(2) *Mononchus brachylaimus* appears to be resistant to bacterial infection under ordinary cultural conditions.

(3) *Mononchus brachylaimus* is provided with particularly strong pharyngeal muscles which enable it to attack successfully a large variety of nemas and devour large numbers within a limited period of time.

This species is not content with small larval forms and has been observed to attack and destroy nematodes fully twice its own size.

(4) *Mononchus brachylaimus* is undoubtedly one of the most voracious of our predatory nematodes as a large percentage of all examined specimens are found to contain ingested remains of one or more phytophagous nematodes.

Apparently it is customary for this species to bolt its victims without much if any effort at mastication as victims swallowed in toto are frequently found outstretched in the lumen of the intestine.

(5) *Mononchus brachylaimus* together with several other nematode species possess a curious oily quality of the cuticle which enables them to float easily upon the surface of fluids.

This characteristic together with the large size of the species facilitates the collection of the material and could doubtless be utilized as an easy means of distribution in the cane irrigation canals should further experimental observation determine the advisability of cultural distribution on the plantations.

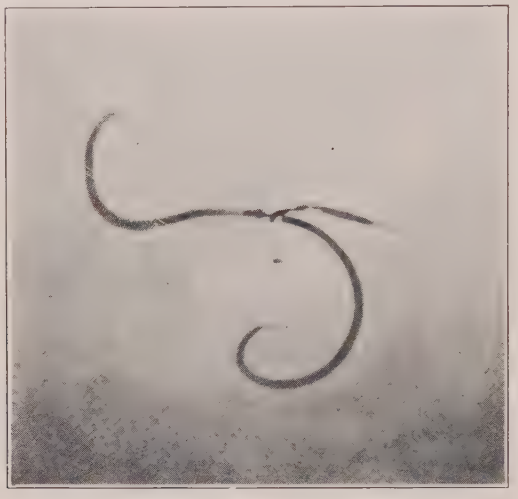


Fig. 5. *Mononchus brachylaimus* attacking a large spear-bearing nematode. Photograph by C. W. Carpenter.

Descriptions and Measurements of Mononchs Identified in the Hawaiian Islands

The eleven species here described have been identified from a limited number of soils and represent only adult forms. Wherever possible the average measurements of 6 females have been taken to give the percentage formula. Larval forms of other Mononchus species have been found in these Islands but identifications will be withheld until adults are available

Mononchus brachylaimus Cobb, 1917.

This species, originally described from Virginia, is now reported for the islands of Hawaii and Oahu, living in the soil of cane and pineapple fields. The average percentage measurements and description of the Hawaiian specimens are as follows:

Female—

			17.		16.	
2.7	7.	23.		61.		88.
2.2	2.5	2.5		3.1		1.8

3.7—4.4 mm.

The truncate head is characteristic of the genus and is surmounted by 6 lips each bearing 4 papillae; the 24 papillae are arranged in two circles, an outer circle

of 18 papillae and an inner circle of 6 papillae. The lateral organs are duplex and are easily seen situated well forward in the anterior half of the pharynx. The oval pharynx is supported by 3 well developed pharyngeal ribs; the pharyngeal muscles of this species are unusually well developed (not shown in figure). The armature consists of 3 onchia: one rather small sharply pointed dorsal tooth is situated dorsally at the base of the pharynx opposed by 2 minute submedian, conical, forward-pointing toothlets. The cylindroid oesophagus widens slightly to receive the lower fourth of the pharynx; delicate cuticular papillae are seen at regular intervals in the oesophageal area, separated by a distance approximately measuring same as body width; the refractile lining measures about one-third the oesophageal diameter and is enclosed by the well developed radial muscles. The nerve ring is situated at about 7 per cent of the total length and is a broad band encircling the oesophagus. The lateral chords are finely granular and measure about one-third the body diameter. The intestine is separated from the oesophagus by a definite constriction and occupies three-fourths of the body width; the intestinal cells are definitely tessellated and the contents granular. The cardia is very plainly visible and is somewhat conical in outline. The vulva is very slightly elevated above the body surface; the vagina is short and placed at right angles to the body wall; the uteri are double joining the reflexed ovarian tubes which are placed upon the right side, and reflexed on the right also; the ovarian tubes contain approximately 14 ova; the ovum is thin-shelled and bluntly elongate measuring about one and one-half times the body width. The arcuate conoid tail tapers gradually to end bluntly with an unarmed spinneret; the tail shows 3 slender dorsal post anal papillae and one ventral papilla. The anus is conspicuous though not protruding. The rectum extends obliquely forwards and inwards and measures approximately the length of the anal body diameter.

Male—

The males are found quite as commonly as the female specimens. The percentage measurements are as follows:

2.6	7.	23.	54.	45.	90.	
			M			3.7—4.0 mm.
2.1	2.3	2.3	2.5		2.	

The paired spicula are arcuate and somewhat broad tapering slightly at the proximal and distal ends. At the anterior end of the spicula a filamentous prolongation is seen passing anteriorly and embracing four large sized rounded nucleated cells which lie anterior and dorsal to it. The accessory pieces are situated along the anal canal and broaden at the distal end forming a sharply bifurcate terminus. Anterior to the anus is a series of 17 supplementary nerve organs. Minute slender papillae may be seen on the dorsal surface of the cuticle occurring at intervals approximately equal to the body width. The testes are anterior and paired, one being slightly longer than the other (45 per cent and 54 per cent of the body length) and are filled with countless numbers of very small oval spermatozoa.

Spermatozoa of the same general appearance are to be found in the female receptaculum seminis (see Fig. 6).

All observations have been made with a 10 occular and a 2 mm. oil immersion objective. Fixative=Fleming's solution. Mounting medium=glycerine jelly.

Minor differences noted between the Hawaiian specimens and the Virginian specimens described by Cobb, 1917, are as follows:

Virginia	Hawaii
Female—One pair innervated papillae near the middle of the tail.	*Female*—Three slender dorsal postanal papillae and one ventral papilla.
Conspicuous papillae in front of, and behind the vulva occupying a distance equal to 2 or 3 times the body diameter.	Slender threadlike papillae situated on the cuticular surface over the oesophageal area. Distance between papillae is approximately equal to the body width.
	Male—The testes are anterior and paired. (45 per cent and 54 per cent of the body length.)
Female—Total length—3.2 mm.	*Female*—Total length—3.7—4.4 mm.
Male—Total length—3.5 mm.	*Male*—Total length—3.7—4.0 mm.

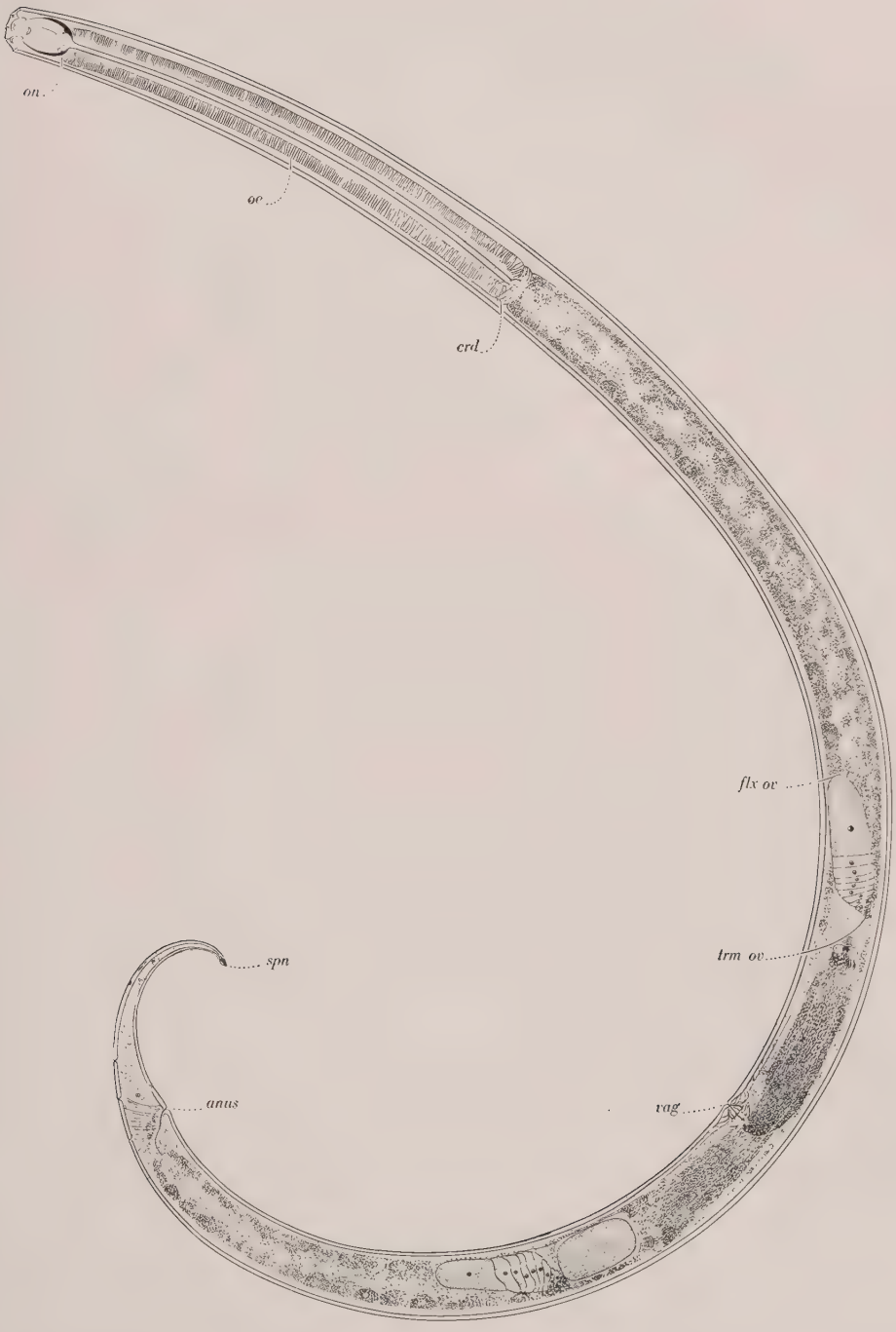


Fig. 6. **Mononchus brachylaimus.**

Adult female. *anus*—anus; *crd*—cardia; *flx ov*—flexure of ovarian tube; *oe*—oesophagus; *on*—dorsal tooth; *spn*—spinneret; *trm ov*—termination of ovarian tube; *vag*—vagina. (× 85).

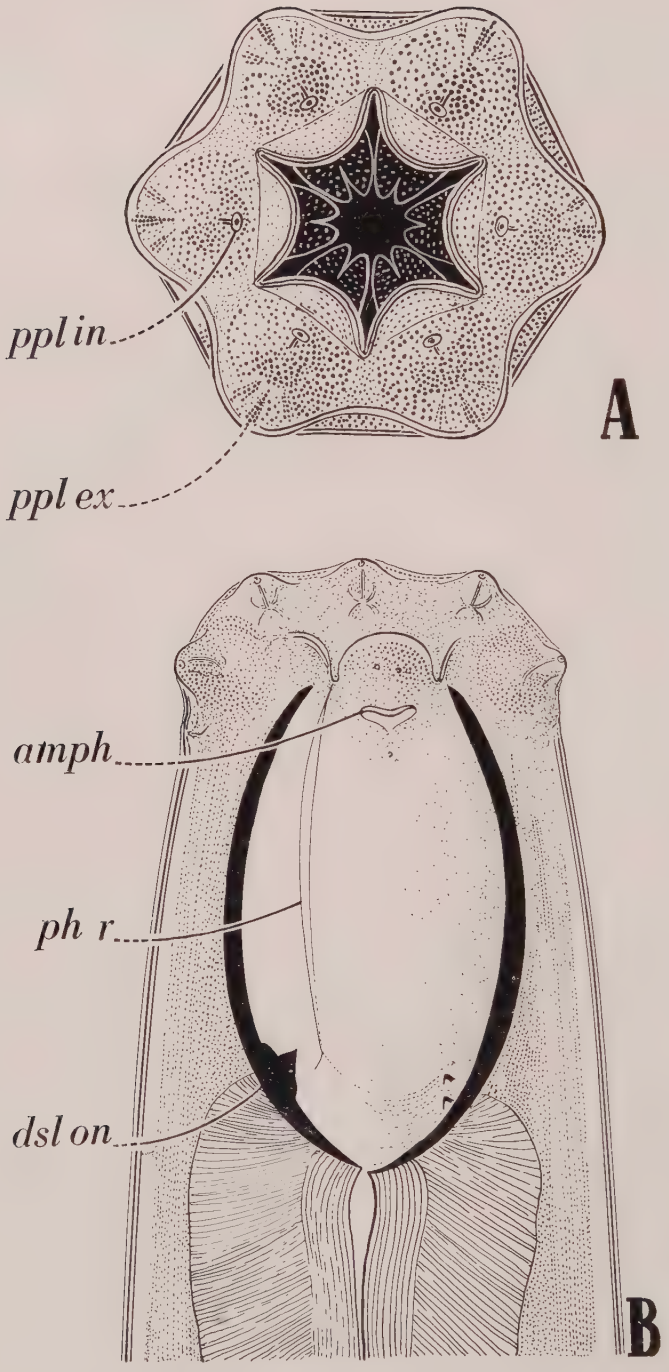


Fig. 7. **Mononchus brachylaimus.**

A. Head on end (adult female). *ppl ex*—outer papilla; *ppl in*—inner papilla.

B. Head end of young female. *amph*—amphid; *dsl on*—dorsal tooth; *ph r*—pharyngeal rib. (× 1000).

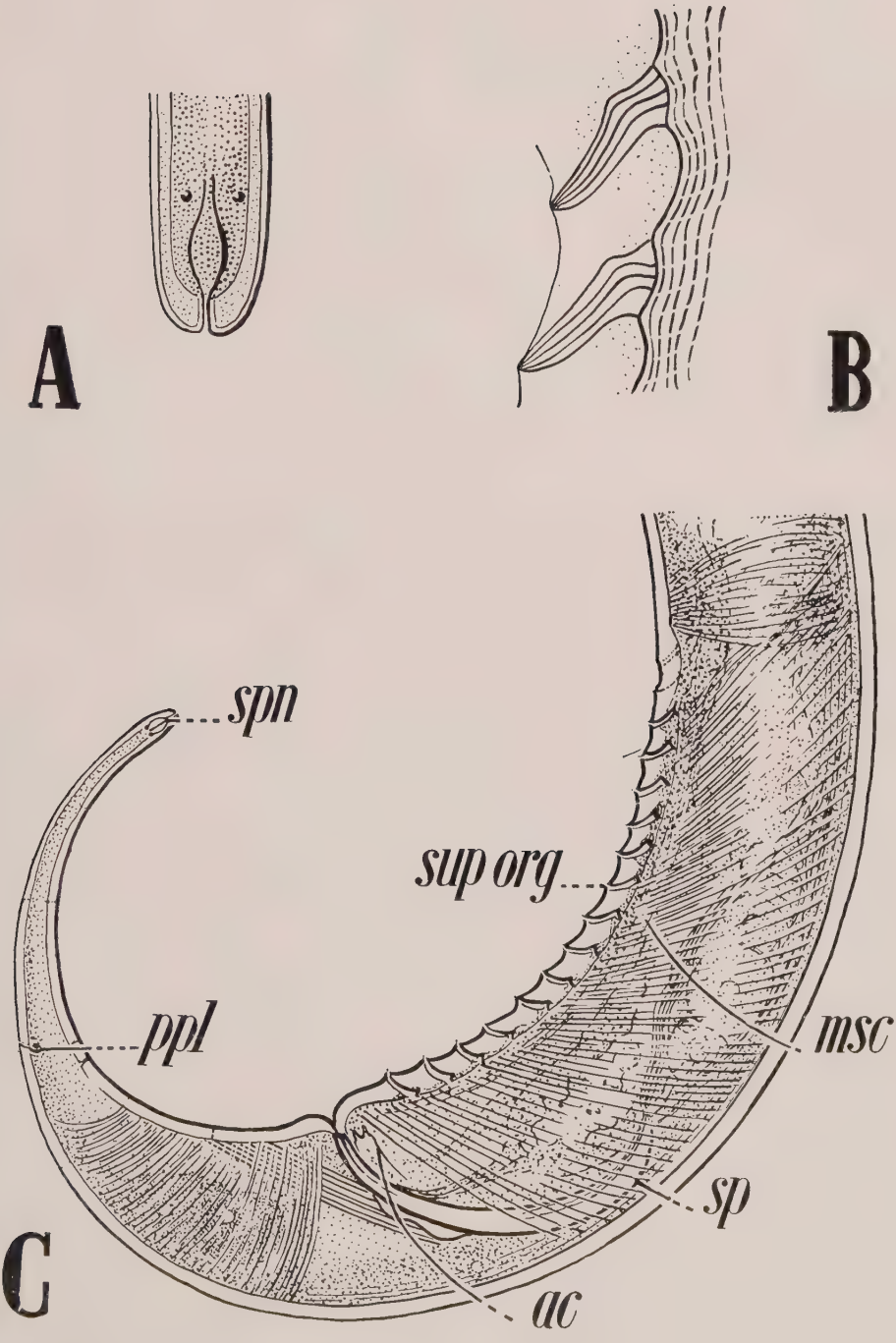


Fig. 8. **Mononchus brachylaimus.** Male.

A. Terminus of tail showing spinneret. (× 1400).

B. Ventral pre-anal body surface showing supplementary organs (× 1400).

C. Tail end of male. *ac*—accessory piece; *msc*—muscle fibres; *ppl*—post-anal dorsal papilla; *sp*—spicula: *spn*—spinneret; *sup org*—supplementary organ. (× 315).

Mononchus cobbi, n. sp.

This species is found in gravelly soils at high elevations on the island of Maui. The average percentage measurements and description are as follows:

			18.	18.	
3.1	9.	29.	68.	93.	1.3 mm.
2.6	—	3.9	3.95	2.6	

These average measurements were obtained from 4 adult females. In no case did the percentage measurement vary more than one per cent. The colorless cuticle shows definite transverse striations. The truncate head is surmounted by 6 lips each bearing 2 papillae. The lateral organs are large, occupying one-third of the width of the anterior third of the pharynx and are somewhat oval with a vaguely discernible rounded base. The pharynx is goblet-shaped and is armed with one rather small dorsal tooth situated midway on the dorsal wall. The cylindroid oesophagus has a refractile lining measuring one-third the width of the oesophageal diameter. The nerve ring is situated transversely across the oesophagus at 8-9 per cent of the body length. A slender pore is present on the ventral side below the nerve ring. The lateral chords are finely granular and measure one-third of the body diameter. The intestine is separated from the oesophagus by a definite constriction, presents a thick walled lumen, large tessellated cells and occupies three-fourths of the body width. The cardia is large and somewhat disc shaped. The vulva presents thick lips and is strongly supported. though not protrusile. The uteri are paired. The ovarian tubes are double and reflexed; the anterior ovarian tube is situated on the left side and contains about 8 ova arranged in single file; the posterior ovarian tube is situated on the right side and contains 10 ova arranged in single file. The arcuate tail is devoid of a spinneret; the anus is plainly marked though not protruding; the thick walled rectum extends obliquely forwards and measures approximately the width of the anal body diameter.

This species is considered highly voracious as a large percentage of all examined specimens was found to contain the ingested remains of one or more nematodes.

All observations have been made with a 2 mm. oil immersion objective and 10 occular. Fixative=mercuric chloride. Mounting media=glycerine jelly.

Fig. 9. **Mononchus cobbi.**

A. Head end of adult female. *amph*—amphid; *oe*—oesophagus; *on dsl*—dorsal tooth; *ppl*—papilla.

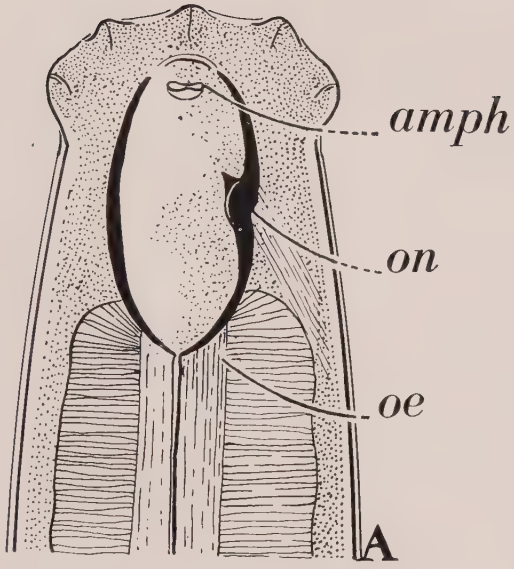
B. Tail end of adult female. *anus*—anus. (× 1020).

Mononchus parvus de Man, 1879.

Originally described in 1879, is reported from Holland and Germany. This species is found on Maui and Hawaii in sandy soils. The average percentage measurements and description for the Hawaiian specimens are as follows:

			15.	15.	
3.	8.5	29.	63.	93.	1 mm.
3.2	4.	4.	4.8	2.6	

The colorless cuticle shows definite striations. The truncate head is surmounted by 6 lips each bearing 2 papillae. The amphid is situated well forward in the ribbed pharynx and is a small transverse slit with slightly clubbed ends and a cupped base. The pharyngeal armature consists of one small dorsal tooth situated about midway in the pharynx; 2 refractile bodies, possibly minute rudimentary submedian toothlets, are faintly discernible at the extreme base of the pharynx. The nerve ring is situated at about 8 per cent of the body length; a small excretory pore is seen opposite the nerve ring. The muscular oesophagus is cylindrical, and possesses a refractile lining measuring about one-third of the oesophageal diameter. The nerve ring is poorly defined and is situated at 9 per cent of the total length. The granular lateral chords are indistinct but estimated to measure approximately one-third the body diameter. The very granular intestine is separated from the oesophagus by a definite constriction; the cells are faintly tessellated. The cardia is indistinct and rounded. The vulva is slightly raised above the body surface and has thick lips; the short vagina has thick walls; the uterus is double; the ovarian tubes are double and reflexed about half-way back to the vulva; each contains about six ova arranged in single file. The anterior ovarian tube is situated on the right side; the posterior ovarian tube is situated on the left side. The anus is not protruding; the short rectum measures approximately two-thirds of the anal body diameter; the tail is arcuate and devoid of a spinneret.



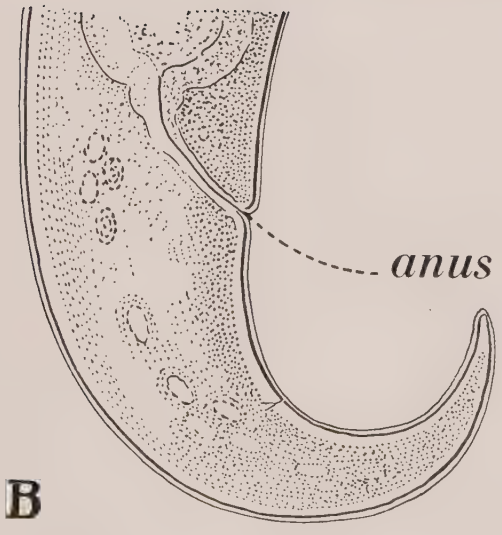


Fig. 10. **Mononchus parvus.**
A. Head end of adult female. *amph*—amphid; *oe*—oesophagus; *on*—dorsal tooth.
B. Tail end of adult female. *anus*—anus. (× 1200).

Mononchus sigmaturus Cobb, 1917.

This species has been reported on the mainland and Mexico and is found in abundance around the roots of sugar cane in certain localities on Oahu.

The average percentage measurements and description of the Hawaiian specimens are as follows:

		18.	18.		
2.3	10.	28.	64.	97.	1.21 mm.
2.	3.	3.	4.6	2.	

The truncate head has 6 well developed lips each bearing 2 papillae. The amphids are easily seen situated transversely to the long axis of the pharynx near the anterior end of the dorsal onchus. A large dorsal onchium is seen placed well forward in the pharynx; 2 small submedian onchia are present and 6 rows of small denticles arranged transversely in the area between the apices of the dorsal and submedian onchia. The nerve ring is difficult to distinguish, is cellular in character and placed at 10 per cent of the total length from the head end. The lateral chords measure one-fourth to one-third the body diameter and are finely granular. The cardiac constriction is plainly seen between the oesophagus and intestine. The intestinal cells are tessellated and the contents granular. The vulva is situated at 64 per cent of the total length and leads into the short straight vagina. The ovarian tubes are double and reflexed; the bluntly oval egg measures .0861 mm. x .042 mm.

The tail is characteristic as it suddenly bends ventrally and narrows behind the anus, forming a cylindroid terminus ending bluntly with an unarmed spinneret. The lips of the anus are very plainly seen though not protruding. An unusually wide dilatator ani muscle is present. The clear walled rectum stretches obliquely forwards and measures approximately the same as the anal body diameter. A slender ventral post-anal papilla is present situated between the ventral curve and the tip of the tail.

Males have not yet been found.

All observations made with a 10 occular and a 2 millimetre oil immersion objective. Fixative=mercuric chloride. Mounting medium=glycerine jelly.

Fig. 11. **Mononchus sigmaturus.**
A. Head end of adult female. *amph*—amphid; *on*—dorsal tooth; *ppl*—papilla.
B. Tail end of adult female. *an msc*—anal muscle; *spn*—spinneret. (× 1100).

Mononchus hawaiiensis, n. sp.

This species is found on Oahu in soils rich in humus. The percentage measurements are as follows:

			15.	15.		
3.	9.	28.	61.		96.	1 mm.
2.5	3.	3.	3.5		3.1	

Very fine transverse cuticular striations may be seen under the highest power. The cylindroid neck is surmounted by a truncate head possessing 6 lips; each lip has 3 papillae (2 outer and 1 inner). The slit-like amphids are exceedingly difficult to define and are situated transversely in the pharynx opposite the apex of the dorsal tooth. Two pharyngeal ribs are seen. The armature consists of one very large dorsal tooth situated well forward in the pharynx, 5 or 6 transverse rows of very small denticles, and 2 small ventral submedian teeth situated at the base of the denticles on the ventral side.

The cylindroid oesophagus receives the lower fourth of the pharynx; the radial musculature becomes coarser in the posterior two-thirds; the refractile lining occupies one-fourth of the oesophageal diameter. The nerve ring is situated at about 9 per cent of the body length. The lateral chords are finely granular and measure one-third of the body width. The intestine is separated from the oesophagus by a definite constriction; the cardia is rounded and shallow; the intestinal cells are not tessellated and the contents are granular. The vulva has very thick lips and is slightly protruded above the body surface; the vagina is short; the uterus double; the ovarian tubes are double and reflexed about three-fourths the distance back to the vulva; the ovarian tubes contain about 8 developing ova. The arcuate tail is acutely bent ventrally a short distance behind the protruding anus. The tail narrows rapidly from the anus and is then cylindroid terminating bluntly in an unarmed spinneret. One ventral pre-anal papilla is present and 2 dorsa-sublateral papillae are situated just posterior to the anus.

All observations were made with a 2 mm. oil immersion objective and a 10 occular.

Fixative=mercuric chloride. Mounting medium=glycerine jelly.

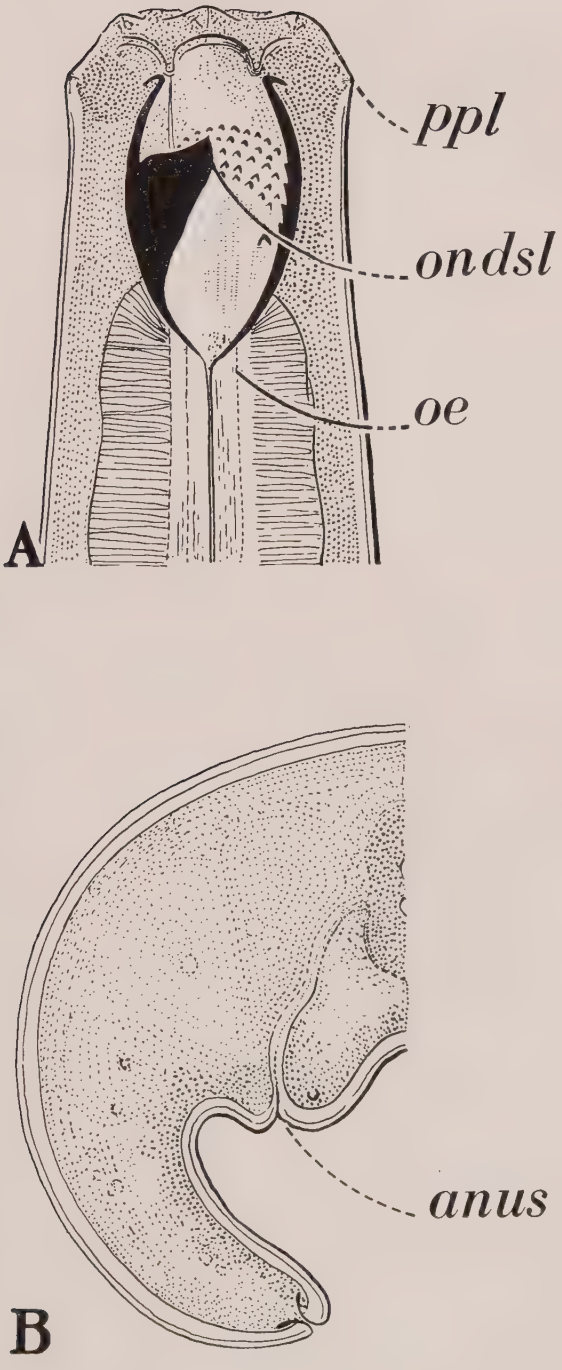


Fig. 12. **Mononchus hawaiiensis.**

A. Head end of adult female. *oe*—oesophagus; *on dsl*—dorsal tooth; *ppl*—papilla.

B. Tail end of adult female. *anus*—anus (× 1400).

Mononchus lacustris, Cobb, 1917.

This species already identified from Michigan, Panama and Florida is found around sugar cane on the islands of Oahu and Maui; also found in pineapple soils on Oahu and on Maui.

The average percentage measurements of the Hawaiian specimens are as follows:

		12.	12.		
2.5	9.	28.	64.	95.	1.3–2 mm.
2.0	4.	4.	4.	2.5	

The cuticle shows slight transverse striations. The cylindroid neck is surmounted by the typical truncate head bearing 6 lips. The lateral organs are oval and cupped at the base, situated transversely to the long axis of the pharynx and placed slightly anterior to the apex of the dorsal tooth. One pharyngeal rib is noticeable in the goblet shaped pharynx. The floor of the pharynx shows transverse striae, especially noticeable at the base. The armature consists of one very large acutely pointed dorsal tooth situated in the anterior half of the pharynx; 2 smaller submedial teeth about the middle of the pharynx, and 6 rows of small denticles arranged transversely in the area between the tip of the dorsal tooth and the basal submedian teeth. The oesophagus is cylindroid with a refractile lining measuring one-third of the oesophageal diameter; the lumen is plainly visible, and the radial musculature well developed. The nerve ring is seen at a distance measuring approximately 9 per cent of the body length and is surrounded by cells. The lateral chords are granular and measure about one-third of the body width. The granular intestine occupies three-fourths of the body and shows faint tessellation. The cardia is broad and somewhat shallow but distinct. The vulva is unusually thick lipped but not protruding and is succeeded by a short vagina entering the double uteri. The ovarian tubes are on the right side, contain approximately 8 ova, and are reflexed about half-way back to the vulva (i.e., one-third of the total length). The egg measures about 1½ times the body width (0.294 x .0485 mm.). The arcuate tail is bluntly conoid. The anus is plainly seen though not protruding. There are 3 large post-anal glands situated in tandem which occupy the width of the body and extend from the rectum down towards the tail. The tail is blunt at the terminus and provided with an unarmed spinneret with a needle shaped valve.

Mounting medium=glycerine jelly. Fixative=bichloride of mercury.

The Hawaiian specimens (1.3-2 mm.) appear to be longer than those found in Michigan (1.1 mm.). This species closely resembles *Mononchus montanus* Thorne, 1924, *Mononchus parabrachyuris* Thorne, 1924, and *Mononchus polonicus* Stefanski, 1915.

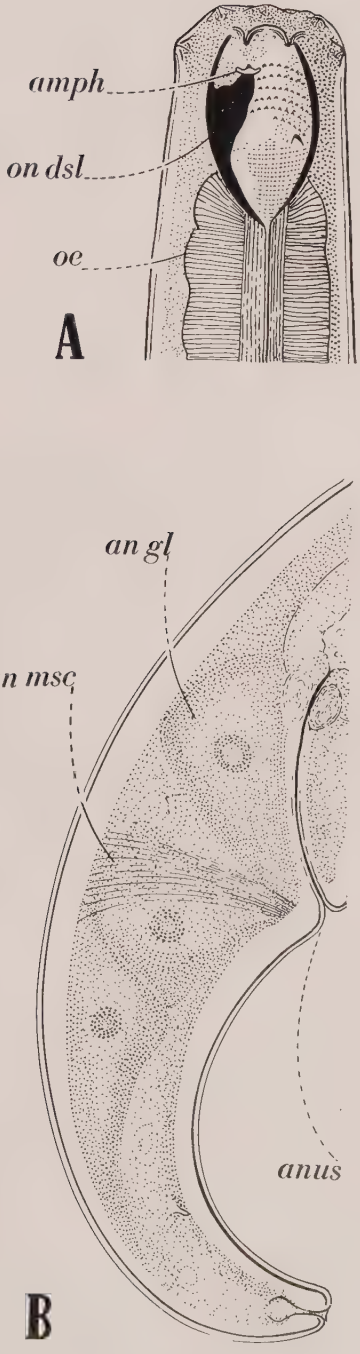


Fig. 13. **Mononchus lacustris.**

A. Head end of adult female. *amph*—amphid; *oe*—oesophagus; *on dsl*—dorsal tooth.

B. Tail end of adult female. *an gl*—anal gland; *an msc*—anal muscle; *anus*—anus. (× 750).

Mononchus muscorum (Dujardin) Bastian, 1866.

This is the oldest species of Mononchus known and has been reported from various parts of Europe and America. The Hawaiian specimens were found in gravelly soil on the slopes of Haleakala at an elevation between 7000-8000 ft.

The average measurements of the Hawaiian species are as follows:

$$\frac{2.3}{2.3} \quad \frac{7.5}{3.} \quad \frac{22.}{3.3} \quad \frac{21.}{60.} \quad \frac{21.}{93.} \quad \frac{}{4.} \quad \frac{}{2.8} \quad 1.8 \text{ mm.}$$

Definite transverse striations may be distinguished in the colorless cuticle. The truncate head is not set off and shows 6 lips provided with an inner and outer circle of papillae. The amphids are clearly seen situated transversely in the anterior half of the pharynx near the apex of the dorsal tooth. The ellipsoidal pharynx is about twice as long as it is wide and shows a well developed pharyngeal rib. The pharyngeal armature consists of a large dorsal tooth, the apex of which is well forward in the anterior half of the pharynx; and a ventral longitudinal rib bearing 14 sharp forward-pointing denticles. The muscular cylindroid oesophagus has a wide refractile lining. The nerve ring is situated at about 7.5 per cent of the total length; a slender pore is visible on the ventral surface opposite the nerve ring. The lateral chords are finely granular and measure about one-third of the body width. The oesophagus is separated from the intestine by a definite constriction; the rounded cardia is plainly visible. The intestinal cells are large and tessellated. The strongly supported vulva is not raised above the body contour; the short vagina extends across one-third of the body width; the uteri are double; the ovarian tubes are paired; the anterior ovarian tube lies on the left side; the posterior ovarian tube lies on the right side, both are reflexed to a distance about half-way back to the vulva; each tube contains approximately 10 ova arranged in single file.

The tail is arcuate and conoid; the anus is plainly visible though not protruding; the rectum extends obliquely forward, measuring about three-fourths of the anal body width. There is no spinneret.

Fig. 14. **Mononchus muscorum.**
A. Head end of adult female. *amph*—amphid; *oe*—oesophagus; *on dsl*—dorsal tooth.
B. Tail end of adult female. *anus*—anus. (× 800).

The following four descriptions of Hawaiian specimens were made by Dr N. A. Cobb:

Mononchus longicaudatus, Cobb. (2)

2.3	7.	24.	54.5	87.5	1.7—2. mm.
2.2	3.1	3.4	3.8	2.4	

The colorless skin is composed of several layers easily distinguishable one from the other, the outer layer being of a chitinous nature and the inner layer composed of powerful-looking muscular tissue. The chitin is not resolvable into striae except with the highest powers. There are no hairs on the surface of the body. The nearly truncate head is continuous with the subcylindroid neck. There are no setae. Six lips arch themselves over the top of the pharynx and bear twelve papillae in two rows of six each, all these papillae being inconspicuous. The lateral organs are inconspicuous, transverse, short, arched slits a little in front of the middle of the pharynx. The species is eyeless. The pharynx and its armature are quite typical, the former being plainly triquetous and the latter consisting of a single dorsal tooth a trifle in front of the middle. There are no other teeth. Obscure markings resembling the teeth of a saw mill file exist on the walls of the pharynx opposite the dorsal tooth. The cylindroid oesophagus contains a thick conspicuous lining and is separated from the intestine by a conspicuous constriction which reduces the diameter to one-half that of the corresponding part of the body. The intestine becomes at once quite two-thirds as wide as the body. There is a distinct cardiac cavity in which the cardia can be plainly seen. The cells composing the intestine are conspicuously and regularly tessellated. The oblique rectum is equal in length to the anal body diameter. The longitudinal fields were not observed. The nerve-ring encircles the oesophagus squarely. The tail is conoid in the anterior half and cylindroid in the posterior half, being in this portion only about one-fourth to one-fifth as wide as at the base. The barely swollen terminus is armed with extremely inconspicuous papillae. The anus is depressed. The vulva, a conspicuous feature on account of the chitinous nature of the vaginal duct, is neither depressed nor raised. The sexual organs are double and are reflexed to near the vulva. They occupy a space equal to the length of the neck.

Habitat. About the roots of diseased cane near Hilo, island of Hawaii, August 20, 1905.

Mononchus longicaudatus has been identified in the soils of cane fields on Oahu, 1926-1931. This species has also been identified in the soils of pineapple fields on Oahu by Dr. H. R. Hagan, Associate Nematologist, Experiment Station of the Association of Hawaiian Pineapple Canners.

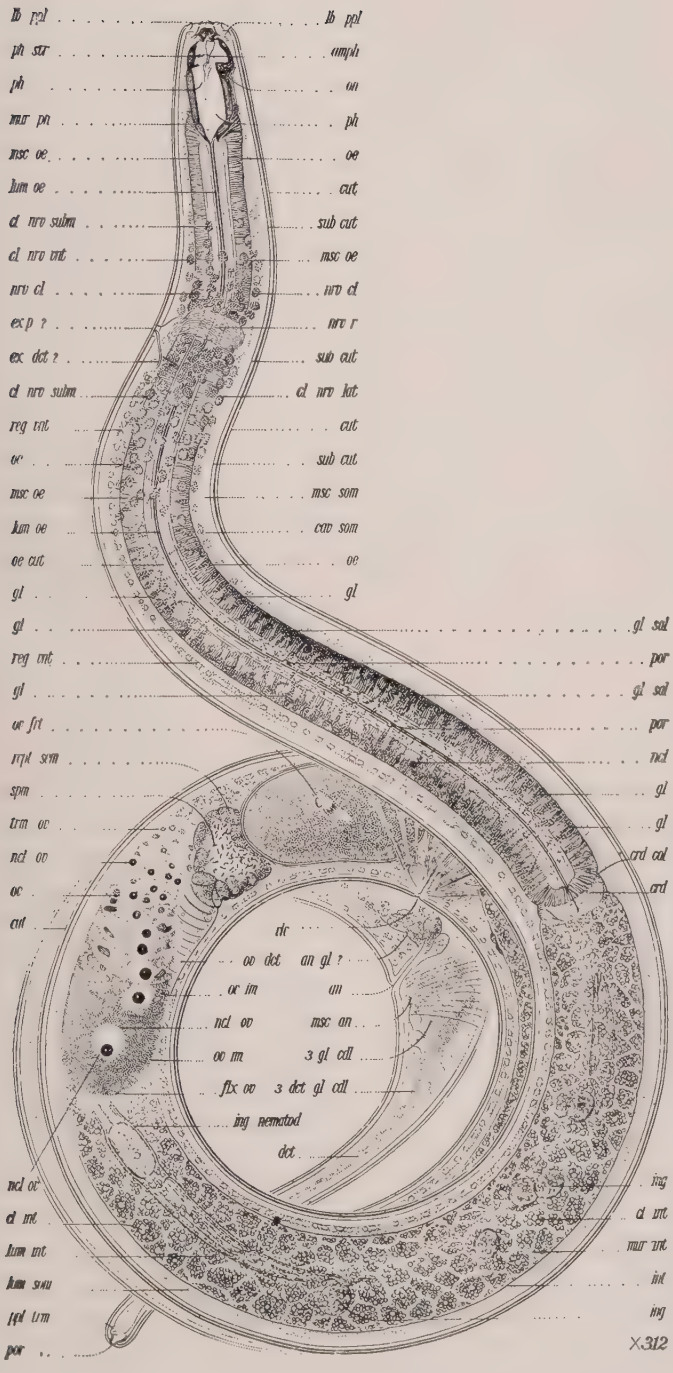


Fig. 15.

After Cobb.

FIG. 2. — Female of a typical mononch, *Mononchus longicaudatus*, a syngonic form. This individual had been feasting on other nemas, the remains of which are shown inside the intestine. Only the anterior half of the sexual organs can be seen in the illustration; an entirely similar branch is hidden on account of the coiled attitude of the body.

The lettering of the illustrations is similar throughout and is explained at the bottom of page 431. The anatomy and histology of various newly discovered features are shown:—

Œsophageal glands (*gl. sal.*), the pore through which the glands empty into the œsophagus (*por.*), syngonic sperm (*spm.*), formation of polar body (*ov. frt.*), ingested protozoon (*ing.*), etc.

* Soil Science, 1917, Vol. III, p. 434.

Mononchus index n. sp. (2)

			15.		
2.1	8.8	30.	69.	95.6	.9 mm.
2.4	3.2	3.5	3.6	2.	

Even the highest powers failed to disclose any markings on the cuticle, the layers of which are comparatively thin. Throughout this description the details are drawn from specimens killed with osmic acid and then mounted in glycerine, hence it is possible that in the fresh condition, markings might be more apparent. There are no hairs on the surface of the body. The neck, which is unusually long, has nearly the same diameter throughout its length, but diminishes with more rapidity opposite the base of the pharynx to form the rather cylindrical truncate head, with a slightly expanded lip region. There are no cephalic setae. Each of the six lips bears two papillae, one on its inner margin, the other on its outer. It is doubtful whether these two papillae have precisely the same function, as they appear to differ somewhat in structure. Lateral organs are indicated by transverse markings bent backwards at the ends. These are opposite the middle of the dorsal tooth. In length they are about equal to half the width of the posterior portion of the pharynx, or about one-fifth the width of the head. There are no eyes. The pharynx is of the sort most commonly observed among the short-tailed species of the genus. The dorsal tooth, located near the middle of the pharynx, is rather massive and is opposed by about five rows of rasp-like teeth, the outer rows being more distinct than the inner. These are placed precisely opposite the point of the dorsal tooth. The pharynx is nearly half as wide as the head and about three times as deep as wide. There are no submedian teeth, the dorsal tooth being the sole occupant of the pharynx. The oesophagus is conoid in its general shape, being anteriorly about half and posteriorly about two-thirds as wide as the corresponding parts of the neck. Throughout its length, the massive lining is very plainly visible, occupying about one-fourth the optical section. The muscular markings are much more visible in the posterior half of the oesophagus than in the anterior half. The cardiac column is rather shallow but is a very distinct constriction. The cardia has a rather peculiar form. In optical section, the posterior contour is pointed, and it seems impossible to attribute this appearance to any shrinkage in the specimen. The intestine becomes at once four-fifths as wide as the body, and as the walls of the anterior portion are rather thin, there is a very distinct and long cardiac cavity. The cells of the intestine are of large size so that few are required to build a circumference. They are filled with scattered granules of pretty uniform size, which give rise to a coarse and rather obscure tessellation. The nature of the ventral gland remains unknown. The rectum is extremely short, being not more than half as long as the diameter of the body just in front of the anus. The longitudinal fields are visible throughout most of the length of the worm, and are about two-fifths as wide as the body. The nerve-ring as is usual in this genus, is well forward. It surrounds the oesophagus squarely, and is about as wide as the oesophagus at the point encircled. The tail is one of the most characteristic features. It has the general contour of a hand folded in the act of pointing with the forefinger, that is, the form of a printer's index or fist. The diameter of the body increases somewhat just in front of the anus and diminishes suddenly at the anus, so that the beginning of the tail is very considerably less in diameter than the portion of the body immediately in front of the anus. Caudal glands are present in the form of three egg-shaped glands located opposite the anus. The length of these glands is about equal to half that of the anal body-diameter. Their secretion is emptied through ducts which terminate at the tail end, which is slightly apiculate and apparently destitute of papillae. The tail, like all other portions of the body, appears to be completely naked. The body musculature ceases at the middle of the tail and the posterior half of this organ is therefore quite transparent. This portion is cylindrical and has a diameter about equal to one-fourth or one-fifth of that of the body at the anus. The vulva is somewhat salient although it is far from being a conspicuous feature. The sexual organ is single and extends forward, the vagina being very short, not over one-fourth as long as the adjacent body-

diameter. The eggs are of large size considering the size of the uterus. A single egg not yet passed on to the uterus was four-fifths to five-sixths as wide as the body and about three times as long as wide. At that stage it had a very thin covering. At a later stage the covering was no thicker. I am not certain whether these eggs do not pass through all the early stages of segmentation before being deposited. I can only suggest from the appearances that this is possible, but unlikely. The ovary is reflexed and reaches a little more than half way back to the vulva.

The male remains unknown.

Habitat. This species was common about the roots of diseased cane, Kipahulu Plantation, Maui, September, 1905. Also Niulii, Hawaii, September, 1905, about the roots of diseased cane.

Mononchus brachyuris Bütschlii. (*2*)

			30.		
2.	7.5	28.2	65.5	96.8	1.92 mm.
2.3	2.9	3.5	3.9	1.9	

The colorless, hairless skin is without markings of any sort. The cylindroid neck ends in a continuous sub-truncate head. There are no setae. The six lips are of the form characteristic of the genus and bear twelve papillae in two rows of six each. The lateral organs consist apparently of transverse slits opposite the middle of the pharynx. This species is eyeless like all others of the genus. The pharynx is one-half as wide as the head and is armed with a single dorsal tooth whose point is located a trifle in front of the middle. It is massive in structure and fills up the pharynx more than is usual in this genus. Rasp-like surfaces exist on the lateral walls of the pharynx opposite the region of this dorsal tooth. Anteriorly the cylindroid oesophagus is one-half as wide as the neck, while posteriorly it is three-fifths as wide. It has the usual thick conspicuous chitinous lining. The conspicuous cardiac column is so deeply constricted as to be only one-half the diameter of the base of the neck. The intestine becomes at once three-fourths as wide as the body. There is a small cardiac cavity in which the cardia can be plainly seen. The cells of the intestine are tessellated. The oblique rectum is equal in length to the anal body-diameter. The longitudinal fields were not clearly seen. The nerve-ring encircles the oesophagus squarely. The tail is conoid to the truncate terminus and contains three caudal glands located opposite to, or a little in front of, the anus. This latter is conspicuous, being somewhat raised. The vulva is a conspicuous feature owing to the thickness of the chitinous walls of the vagina, which is one-half as long as the body-diameter. The sexual organs are double and occupy a space two-thirds as long as the neck. The eggs are probably ellipsoidal, but not much elongated. The sexual organs are reflexed.

Habitat. About the roots of diseased cane, Hilo, island of Hawaii, August 20, 1905.

Mononchus brachyurus has been identified in the following locations on the islands of Oahu and Maui, 1926-1931.

Fields of Honolulu Plantation Company (around the roots of sugar cane); Kaimuki (garden soil); Moanalua Gardens (garden soil); fields of Waialua Agricultural Co., Ltd., (around roots of sugar cane and pineapples); fields of Hawaiian Commercial and Sugar Company, Ltd. (around the roots of sugar cane); slopes of Haleakala at an elevation of approximately 7000 feet (around the roots of *Taraxacum officinale,* [dandelion] Weber.).

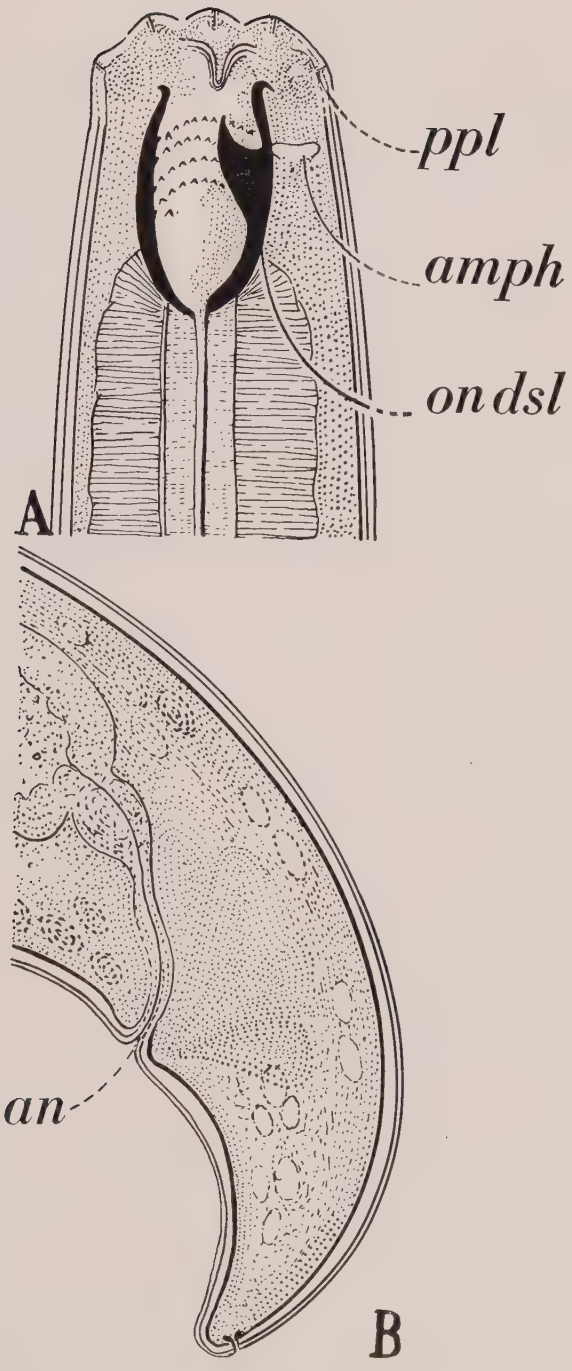


Fig. 16. **Mononchus brachyuris.**
A. Head end of adult female. *amph*—amphid; *on dsl*—dorsal tooth; *ppl*—papilla.
B. Tail end of adult female. *an*—anus. (× 1400).

Mononchus papillatus, Bastian. (3)

3.	9.3	26.	62.	27.	93.	
2.6	3.5	3.8	4.3	—	2.4	1.1 mm.

Glands are present in the segments of the oesophagus, and are most strongly developed in the posterior half. The secretion of the glands in the dorsal segment pours into the lumen of the oesophagus through a minute pore near the middle of the neck, a short distance behind the nerve ring. Under favorable conditions lenses of the highest power show transverse striae to be interrupted on the lateral lines, where there are two refractive longitudinal striations very close together. What appears to be an ordinary ventral renette pore is found a short distance behind the nerve-ring. The writer's investigations prove this species to be syngonic. The longitudinal ribs of the pharynx, probably three in number, are a little more prominently developed than usual. Occasionally a subventral or submedian rib of the pharynx shows traces of most exceedingly fine denticles. Only the most careful examination of favorable specimens shows these denticles. The writer has never observed a denticulated ventral rib like that of *muscorum* as mentioned by Menzel.

A common, voracious, cosmopolitan, nemativorous species. Found in many parts of Europe and of the United States, and also in Hawaii, Australia, South America and Asia.

Specimens of this species have been identified (1926-1931) in soils of cane and pineapple fields, Oahu and Maui.

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(2) Cobb, N. A. 1906. Fungus maladies of the sugar cane. Bull No. 5, Div. of Path. & Physiol., H. S. P. A. Expt. Sta., pp. 179-182.

(3) Cobb, N. A. 1917. The Mononchs. Soil Science, III, p. 458.

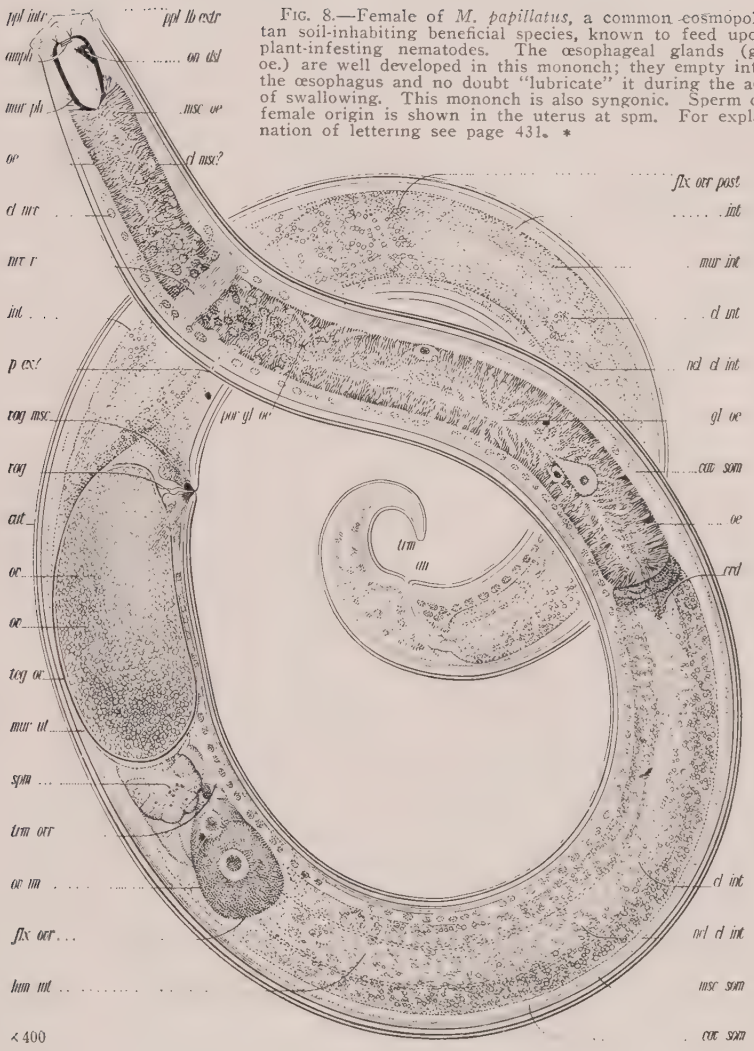

Fig. 17.

After Cobb.

FIG. 8.—Female of *M. papillatus*, a common cosmopolitan soil-inhabiting beneficial species, known to feed upon plant-infesting nematodes. The œsophageal glands (gl. oe.) are well developed in this mononch; they empty into the œsophagus and no doubt "lubricate" it during the act of swallowing. This mononch is also syngonic. Sperm of female origin is shown in the uterus at spm. For explanation of lettering see page 431. *

* Soil Science, 1917, Vol. III, p. 441.

Steer "Dry Lot" Fattening Experiment

By V. Eremeef and C. G. Lennox

Location: Conducted at Waianae Company from June 15, 1928, to September 1, 1928. The feeding was under the supervision of V. Eremeef, of Waianae Company.

Object: To finish off feeder steers in a dry lot using a mixture of molasses, bagasse and protein supplement as a complete feed ration. The ration used was substantially the same as that employed by the Honokaa Sugar Company in feeding plantation work animals. A description of the feeding at Honokaa was published by W. P. Naquin in the *Hawaiian Planters' Record*, October, 1929.

Equipment: Twelve steers were penned in a corral approximately 200'x200' in size. Abundance of shade and wind protection was afforded by trees growing in the corral. A good supply of water was present at all times. A cattle chute was built on one side of the corral with a large platform scales placed in the center. The steers were run through the chute singly and held on the scales until correctly weighed and then released.

Progress Notes: June 14, 1928. Twelve steers were selected from a herd which had been grazing on the Waianae kiawe range land. The animals ranged from small yearlings to big three-year olds. They were not in good flesh and were quite wild.

Nine of the animals were half Polled Angus and half nondescript. Two showed evidence of Short Horn blood, and one was nondescript. The entire 12 were driven into the above-mentioned corral.

June 15, 1928. Weighed 11 steers. One escaped over the corral fence and was never returned.

June 15-22, 1928. The feeding of the bagasse mixture was made gradual by feeding a quantity of cane tops with it during the first week. The lighter mixture of Formula I (see Table) was fed during the first week.

Starting the second week the steers were given nothing but the mixture of Formula II (see Table). They were given no other feed except this.

August 21, 1928. Steers weighed a second time. Only 10 were weighed as one had escaped. Formula changed at this date to Formula III which was more concentrated.

September 11, 1928. Steers weighed a third time. One was too elusive so only 9 were weighed. Experiment discontinued.

Discussion: During the progress of the experiment the steers were disturbed as little as possible. They were in a clean, dry paddock well shaded and always supplied with fresh water and rock salt. The bagasse mixture was placed in feeding troughs in the early morning and late afternoon. The amount put in was governed by the amount left by the previous feeding, it being desirable to have only a very small quantity left over.

In round figures each steer ate about 25 pounds of the mixture daily, or 50 quarts.

The cost figures on such an experiment would likely be quite misleading since so much of the work had to be done by trial and error until a satisfactory technique was established. The cost of mixing the feed could be greatly reduced if a factory was equipped to do such work. In this case a small concrete mixer was used which was slow and costly.

A table is presented showing the approximate cost per pound gain of steers. This figure represents only the feeding ingredients used.

No estimate has been made of cost of mixing, overhead, interest on investment, loss of animals by death and other charges which would raise the total cost per pound gain by a considerable margin.

Summary: Ten steers were fed in a dry lot on a "finishing off" ration of molasses, bagasse and soy bean meal. During the period of the experiment (89 days) the daily gain per steer was approximately 3 pounds per day. At the start of the experiment the steers were thin and shaggy, at the end they were well rounded and shiny. The daily gain in the first period was slightly greater in the first 67 days than in the second 22 days of the experiment, even though the mixture in the second period was more concentrated. The economic length of a "finishing off" period could be best determined by further experimentation.

The results of this experiment are presented as a lead to a profitable use of molasses. Further experiments along this same line should be conducted before adoption as a commercial proposition.

Formulas used—No. of pounds of each ingredient per concrete mixer full.

Ingredients	Formula I	II	III
Bagasse	24	24	24
Molasses	32	48	52.5
Soy bean meal	7	9.6	9.6
	63	81.6	86.1

Analysis of materials.

Materials	Dry Matter	Per 100 Pounds of Material: Digestible Crude Protein	Per 100 Pounds of Material: Total Digestible Nutrients
Molasses	74.3	1 to 2	39.5 to 53
Soy bean meal	90	38.6	82.6
Bagasse analysis approx.	75	.4	46.3

Analysis of Formulas I and III in terms of 100 lbs. of mixture.

Formula I	D. M.	D. C. P.	T. D. N.	Nutritive Ratio	Weight per Quart
50.8 pounds molasses	37.8	.76	28		
11.1 pounds soy bean meal	10	4.3	9.2		
38.1 pounds bagasse	28.6	.15	17.6		
100	76.4	5.21	54.8	10.5	½ pound
Formula III					
61 pounds molasses	45.4	.91	33.6		
11.1 pounds soy bean meal	10	4.3	9.2		
27.9 pounds bagasse	21	.11	12.9		
100	76.4	5.32	55.7	10.5	

Table of Feed Consumption and Costs.

Period 1—June 15 to August 21, 1928.

Formula II used at the rate of approximately 250 pounds of mixture per day.
Approximately 8¼ tons of Formula II consumed.

Bagasse	2.43 tons	at $ 2.98	per ton	= $ 7.25
Molasses	4.85 tons	at 5.00	per ton	= 24.23
Soy bean meal	.97 ton	at 62.00	per ton	= 60.01
	8.25 tons			$91.49

No. of pounds gained by steers.....2072
No. of pounds feed consumed per pound gain in weight.....7.96
Feed cost per pound gain in weight.....$.044

Period 2—August 21 to September 11, 1928.

Formula III used at rate of approximately 250 pounds of mixture per day.
Approximately 2½ tons of Formula III consumed.

Bagasse	.697 ton	at $ 2.98	per ton	= $ 2.08
Molasses	1.521 tons	at 5.00	per ton	= 7.60
Soy bean meal	.279 ton	at 62.00	per ton	= 17.30
	2.50			$26.98

No. of pounds gained by steers..... 582
No. of pounds feed consumed per pound gain in weight.....8.6
Feed cost per pound gain in weight.....$.0464

Record of Steer Weighings.

	Description of Steer	June 15/28	Aug. 21/28	Sept. 11/28
1.	Black—white spot on left hind leg.....	460	749	770
2.	Pure black—biggest—longer head.....	745	872	927
3.	Black—white face	765	792	825
4.	Pure black—smallest	230	480	547
5.	Brown—broken triangle on forehead.....	500	795	878
6.	Brown—perfect triangle on forehead.....	455	687	768
7.	White	455	649	732
8.	Black—white spot on belly	295	461	574
9.	Black—shaggy brown tinge—sign of horns..	410	687	...
10.	Black—small—spotted white face.....	261	487	533
	Total.....	4587	6659*	6554

Computation of daily gain in weight.

	Period No.	Total Gain in Weight	No. Steers	Gain per Steer	No. Days	Pounds Gain per Day per Steer
1.	June 15-Aug. 21	2072 pounds	10	207.2 pounds	67	3.09
2.	Aug. 21-Sept. 11	582 "	9	64.7 "	22	2.94

* In computing for period No. 2, Steer No. 9 is omitted and the total used is 5972 instead of 6659.

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
MARCH 16 TO JUNE 9, 1931

Date	Per Pound	Per Ton	Remarks
Mar. 16, 1931	3.20¢	$64.00	Philippines, Cubas.
" 17	3.25	65.00	Cubas, Philippines, Porto Ricos.
" 18	3.245	64.90	Philippines, 3.23, 3.26.
" 19	3.31	66.20	Philippines, 3.30; Porto Ricos, 3.30, 3.32.
" 24	3.345	66.90	Philippines 3.34, 3.35; Porto Ricos, 3.35; Cubas, 3.35.
" 26	3.35	67.00	Porto Ricos, Philippines.
" 30	3.33	66.60	Cubas.
Apr. 8	3.35	67.00	Porto Ricos.
" 13	3.33	66.60	Philippines.
" 15	3.31	66.20	Porto Ricos, 3.32, 3.30.
" 16	3.28	65.60	Porto Ricos.
" 17	3.27	65.40	Philippines.
" 20	3.275	65.50	Cubas, 3.30; Philippines, 3.25.
" 21	3.25	65.00	Philippines, Porto Ricos.
" 23	3.27	65.40	Porto Ricos.
" 25	3.25	65.00	Philippines.
" 28	3.20	64.00	Porto Ricos.
" 30	3.22	64.40	Porto Ricos.
May 1	3.235	64.70	Philippines.
" 4	3.21	64.20	Philippines, 3.22, 3.20.
" 5	3.20	64.00	Porto Ricos.
" 6	3.145	62.90	Philippines, 3.15; Porto Ricos, 3.15, 3.14.
" 8	3.16	63.20	Philippines, 3.14; Cubas, 3.18.
" 11	3.18	63.60	Porto Ricos.
" 15	3.20	64.00	Porto Ricos.
" 16	3.23	64.60	Philippines.
" 18	3.24	64.80	Porto Ricos, 3.23; Philippines, 3.25.
" 20	3.20	64.00	Philippines.
" 21	3.16	63.20	Philippines.
" 22	3.15	63.00	Porto Ricos.
" 26	3.125	62.50	Porto Ricos, 3.11, 3.14; Philippines, 3.13, 3.12.
" 28	3.16	63.20	Philippines, 3.15, 3.17.
" 29	3.215	64.30	Philippines, 3.20; Porto Ricos, 3.20, 3.23.
June 1	3.24	64.80	Porto Ricos, 3.23, 3.25; Philippines, 3.23, 3.25.
" 2	3.235	64.70	Porto Ricos, 3.24; Philippines, 3.24, 3.23.
" 4	3.20	64.00	Philippines.
" 5	3.25	65.00	Porto Ricos.
" 9	3.30	66.00	Cubas, Philippines, Porto Ricos.